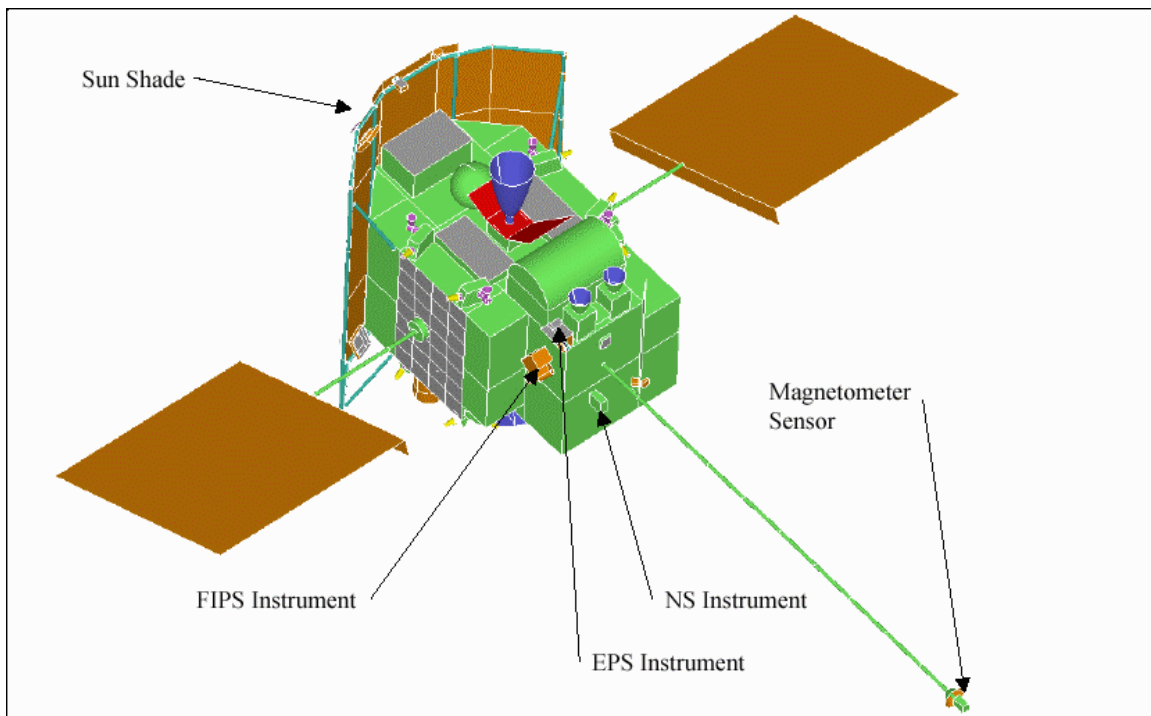# MESSENGER:
Software Interface Specification
for the Calibrated Data Records
of the Magnetometer

Version 3c

Prepared by:

Haje Korth
Johns Hopkins University
Applied Physics Laboratory
1100 Johns Hopkins Rd.
Laurel, MD 20723

Document Review

This document and the archive it describes have been through PDS Peer Review and have been accepted into the PDS archive.

Haje Korth, MESSENGER MAG Instrument Scientist, has reviewed and approved this document.

Steve Joy, PDS PPI Node Representative, has reviewed and approved this document.

Susan Ensor, MESSENGER Science Operations Center Lead, has reviewed and approved this document.

Change Log

DATE	SECTIONS CHANGED	REASON FOR CHANGE	REVISION
6/14/11	Change Log	Added change log.	V2c
6/14/11	5.2.1	Added previously omitted RTN coordinate description.	V2c
	6.8	Updated directory structure to reflect organization by coordinate system, year, and month.	
12/13/11	5.2	Added description of AG CDRs.	V3a
	6.2	Updated file naming convention to include desginators for AC data.	
	6.3.6	Added content description for AC CDR ASCII table.	
	6.6	Added data volume estimate for AC CDRs.	
	6.8	Updated directory structure to include tree for AC CDRs.	
	8.6	Inserted PDS label for AC CDRs.	
1/9/12	5.2.2	Minor text update.	V3b
	6.2	Re-ordered coordinate system for consistency with section 6.3.	
	6.3.3	Added VSO coordinates.	
	6.3.5	Corrected misspelling in filenaming convention.	
5/26/12	2, 7	Change "Data Management and Science Analysis Plan" to "Data Management and Archiving Plan" Refer to Data Management and Archiving Plan for PDS release schedule and remove schedule, Table 3, from this document.	V3c

Table of Contents

1. Purpose and Scope of Document

1.1 Purpose

This document will serve to provide users of the MESSENGER Magnetometer (MAG) data products with a detailed description of the generation, validation, and storage of Calibrated Data Record data products from the MAG instrument (see Figure 1). The MESSENGER MAG data products are deliverables to the Planetary Data System (PDS) and the scientific community that it supports. All data formats are based on the PDS standard.
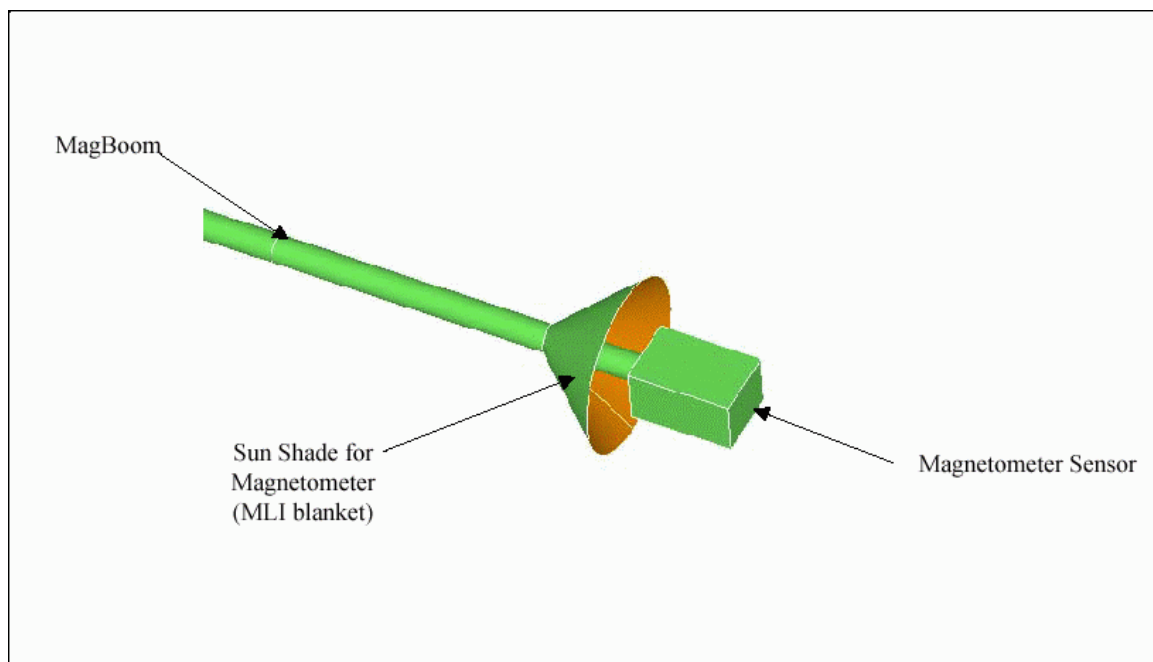
Figure 1: MAG Instrument.

1.2 Scope

This Software Interface Specification (SIS) is useful to those who wish to understand the format and content of the MESSENGER Magnetometer Calibrated Data Record (CDR) data products. Typically, these individuals include software engineers, data analysts, and planetary scientists. The SIS applies to CDR data products produced during the course of the MESSENGER mission. Reduced Data Records (RDRs) are outside the scope of this SIS and will be described in a separate SIS document – the MAG RDR SIS.

In addition this SIS describes the MAG documentation volume, which will contain products related to the EDR, CDR, and RDR level archives. The contents of the documentation volume will provide the information needed to understand and use the EDR, CDR, and RDR data products for science analysis. Sufficient information to allow

investigators to generate CDR-level data from the EDR products is provided in the accompanying document MAG_EDR2CDR.PDF. This document includes calibration conversion tables, time latency correction values, and offset corrections as well as descriptions of the algorithms for their use, including key sections of high-level source code to accurately capture critical logic or routine call sequences. The information specifically excludes software that must be executed to be useful. The documentation volume is described in greater detail in section 6.6.

The CDR magnetic field data are medium-level processed data and are produced from low-level Experimental Data Record (EDR) data. The CDR products contain magnetic field data, which have been converted to physical units, transformed into physical coordinate systems, and tagged with time stamps and spacecraft location. Release notes contain data quality and ancillary information for each CDR product that allow exact reconstruction of the EDR-to-CDR conversion. All data processing steps from the EDR to the CDR level are reversible, i.e., the EDRs can be reconstructed from the CDR data. This is in contrast to the RDR data to be published at a later time, where irreversible data reduction techniques such as averaging will be applied. The CDR processing steps and algorithms are described in the calibration description given in the companion document MAG_EDR2CDR.PDF, which will be replaced by the in-flight calibration paper when it becomes available. Appropriate updates to the MAG documentation volume such as tables of calibration parameters required to convert from EDR to CDR products will be made as they are derived and validated.

2. Applicable Documents

The following documents are relevant to the MAG CDR SIS and are referenced herein:

- MESSENGER Mercury: Surface, Space Environment, Geochemistry, Ranging; A mission to Orbit and Explore the Planet Mercury, Concept Study, March 1999. Document ID number FG632/ 99-0479
- Planetary Data System Standards Reference, March 20, 2006, Version 3.7, JPL D-7669, Part-2.
- Planetary Data System Archive Preparation Guide, August 29, 2006, Version 1.1, JPL D-31224.
- MESSENGER Data Management and Archiving Plan, The Johns Hopkins University Applied Physics Laboratory. Document ID number 7384-9019
- [PLR] Appendix 7 to the discovery program Plan; Program Level Requirement for the MESSENGER Discovery project; June 20, 2001.
- MESSENGER: Software Interface Specification for Experimental Data Records of the Magnetometer, The Johns Hopkins University Applied Physics Laboratory, September 25, 2006.
- B. J. Anderson et al., The Magnetometer Instrument on MESSENGER, Space Sci. Rev., 131, 417-350, doi:10.1007/s11214-007-9246-7, 2007.
- Temporary calibration description MAG_EDR2CDR.PDF, to be replaced by in-flight calibration paper once available.

3. Relationships with Other Interfaces

The MAG CDR data products are hosted at the Science Operations Center (SOC). The data products will be electronically transferred to the PDS Planetary Plasma Interactions (PPI) Node according to the delivery schedule in the MESSENGER Data Management and Archiving Plan. The data within the CDR files are stored in PDS ASCII TABLE objects.

4. Roles and Responsibilities

The roles and responsibilities of the instrument teams, the Johns Hopkins University Applied Physics Laboratory (APL), Applied Coherent Technology (ACT), and the Planetary Data System (PDS) are defined in the MESSENGER Data Management and Archiving Plan.

5. Data Product Characteristics and Environment

5.1 Overview

The primary objective for the MAG instrument is to gather data to determine the structure of Mercury's magnetic field. To do this, the instrument will make comprehensive measurements of the strength and geometry of the magnetic field. The data will also resolve fields due to magnetosphere currents which reflect the structure and dynamics of Mercury's magnetosphere. Finally, the MAG data will support particle measurements made by the Energetic Particle and Plasma Spectrometer (EPPS). An overview of the MAG instrument is provided in section 8.8 and a detailed description can be found in *Anderson et al.* [2007].

5.2 Data Product Overview

This document contains information on the MAG CDR products. Currently, two types of MAG CDR products are derived, one from the Science EDRs and one from the AC EDRs. Furthmore, for each Science EDR between 3 and 5 CDR files are produced depending on mission phase to represent the data in various coordinate systems applicable to the environment. Each MAG CDR data product consists of two files. The first file contains the data in ASCII table fixed format. The second file is a detached PDS label file, which describes the contents of the ASCII table file. The label file defines the start and end time of the observation, product creation time, the structure of the ASCII table and each of the different fields within the table. The label file also contains the release notes for the data file, giving ancillary information used for the CDR conversion, such as calibration parameters and SPICE kernels, and the data quality assessment. One set of these two files contain the observations collected on a given UTC day in a given coordinate system.

5.2.1 Science CDR Products

The Science CDRs provide the primary science MAG data and consist of calibrated 3-axis field samples from the magnetometer at the commanded sample rate. The processing steps for the CDR products, described in detail in MAG_EDR2CDR.PDF, include:
1. accounting for time latency between the registered and actual (physical) time of the observation;

2. conversion from spacecraft mission elapsed time (MET) to UTC;
3. subtraction of the magnetometer offsets for each axis;
4. conversion from engineering units to physical units;
5. transformation from sensor to spacecraft coordinates;
6. transformation of the vector magnetic field to geophysical coordinate systems;
7. assignment of data quality flags.

The vector field data are transformed into the following geophysical coordinate systems:

1. Sensor and spacecraft coordinates as defined in Figure 2. The transformation between the two coordinate systems is reported in the magnetometer instrument paper [*Anderson et al.*, 2007];
2. J2000 coordinates, defined with +X pointing toward the mean vernal equinox, +Z pointing along the mean rotation axis of the Earth on 1 Jan 2000 at 12:00:00.00 Barycentric Dynamical Time (TDB), which corresponds to JD 2451545.0 TDB, and +Y completing the right handed system;
3. Radial-Tangential-Normal (RTN) coordinates, defined as +R pointing from the Sun to the spacecraft, +T pointing in direction of the cross-product of the Sun spin axis and the Sun-to-spacecraft vector, and +N completing the right-system and is positive to the north;
4. Mercury solar orbital (MSO) coordinates, defined as +X pointing from Mercury center toward the Sun, +Z pointing northward perpendicular to Mercury's orbital plane, and +Y completing the right handed system. Venus-centered Venus solar orbital (VSO) coordinates are similarly defined. Solar orbital coordinates are only available for planetary flyby and orbital data;
5. Mercury body fixed (MBF) coordinates, Cartesian X, Y, Z coordinates defined relative to the planet's center, with +Z parallel to Mercury's rotation axis directed to the north ecliptic, +X directed to the prime meridian in the equator (0º latitude), and +Y completes the right handed system. Body fixed coordinates are only available for planetary flyby and orbital data.

The CDR products with the field in sensor and spacecraft coordinates contain UTC, MET, magnetometer range, sample rate, and magnetic field vectors in spacecraft and sensor coordinates. CDR products in J2000, RTN, MSO, and MBF coordinates include UTC, MET, spacecraft position and the magnetic field vector in the respective coordinate system. The MET used in the MAG CDRs is a derived quantity as defined in section 6.3.
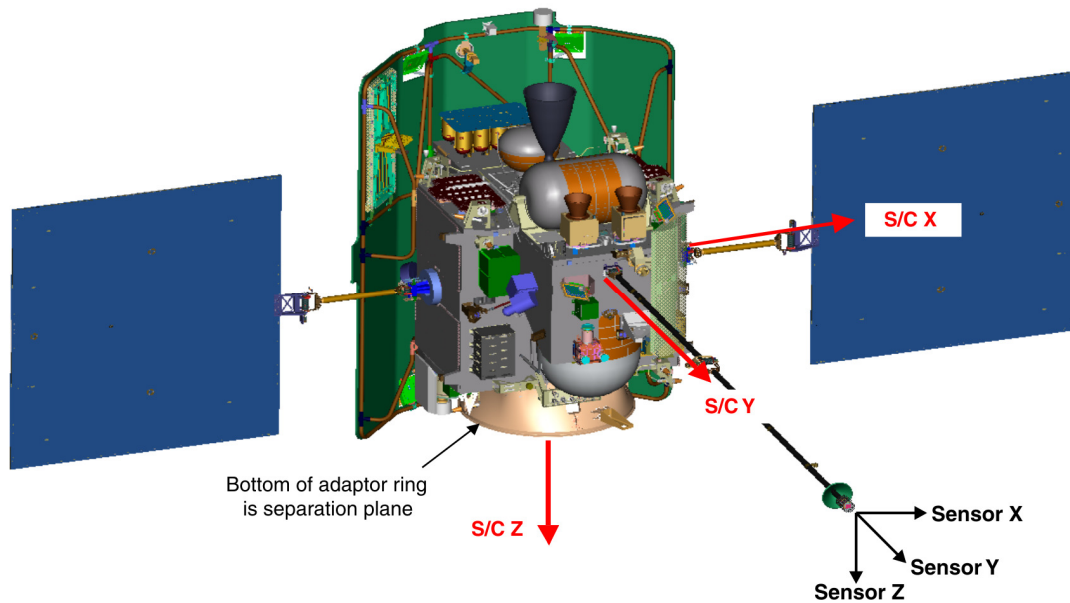
Figure 2: Spacecraft and MAG sensor coordinates.

5.2.2 AC CDR Product

The AC CDR provide ancillary MAG data and contain calibrated alternating current (AC) values of the average output amplitude a 1-to-10 Hz bandpass filter for a single magnetometer axis selected by command. To conserve telemetry, the vector sampling will usually be less than the maximum rate, 20 samples/s. To provide a record of the amplitude of fluctuations for frequencies higher than 1 Hz, an AC amplitude is calculated from the internally sampled 20/s data for the sensor axis commanded as the AC_AXIS. The 1 to 10 Hz bandpass average amplitude is evaluated for the commanded sensor axis and recorded as a log AC value with a 4-bit mantissa of the four most significant non-zero bits and a 4-bit power of two exponent of the 4th (least significant) bit of the mantissa. This is called the logAC value. It is created once per second and saved for telemetry at that rate or at the commanded science rate, whichever is less frequent. This data product has proven to be very useful to the MAG Team in detecting magnetospheric boundary crossings manifested in sudden changes in the amplitude of the magnetic field fluctuations without the need for spectral analysis of the science data products.

The processing steps for this CDR product are the conversion of time tags from spacecraft mission elapsed time (MET) to UTC and the application of the selected-axis scale factor, which is listed in the document MAG_EDR2CDR.PDF.

5.2.3 Additional CDR Products

Additional CDR products may be defined in the future and this description will be updated when these products become available.

5.3 Data Processing

5.3.1 Data Processing Level

The data processing levels are as follows. All data levels refer to CODMAC definitions reproduced in the Appendix. The spacecraft data downlink is telemetered through NASA's Deep Space Network (DSN) managed by the Jet Propulsion Laboratory in Pasadena, CA, and then forwarded to APL. At APL, these data are transmitted to the MESSENGER Science Operations Center (SOC), operated jointly by APL and ACT and located at APL, in the form of CCSDS packets (Level 1 data). The Level 1 MAG raw time series and engineering data are then broken out of the data stream and stored online at the SOC. The Level 1 data are then ingested by an automatic data processing system to generate Level 2 data (EDRs), which are stored in a database reserved for the MAG sensor. Subsequently, the Level 2 data are processed to Level 3 data (CDRs) containing calibrated, UTC time-tagged observations in various coordinate systems and stored at the SOC. Each product has a unique file name and conforms to the file naming convention in section 6.2.

5.3.2 Data Product Generation

The MAG CDR production is implemented at the SOC using data processing routines supplied by the MAG team. The routines apply pre-flight gain and matrix conversion calibrations to the EDR raw data, convert the time stamp from MET to UTC, query SPICE kernels for the spacecraft position, transform the position and vector field into various reference systems using the spacecraft attitude and position data accessed via the corresponding SPICE kernels as described in section 5.2.1, and store these data in the proper PDS labeled format. The processing steps are described in detail in the preliminary calibration document MAG_EDR2CDR.PDF. The CDR data products are available to the MESSENGER Science Team for initial evaluation and validation via the SOC web site. At the end of the evaluation and validation period, the data are organized and stored in the directory structure described in section 6.8 for transmittal to the PPI Node. The transmittal process is described in section 5.3.3. The CDR delivery to the PDS will be accompanied by an update to the documentation volume.

The MAG CDR data processing flow is outlined in Figure 2. MAG CDR processing is automated and continuously probes the availability of updated calibration parameters and newly-arrived EDRs at the SOC. The MAG calibration includes parameters, which are periodically updated following in-flight calibration activities. If updated calibration parameters are available, the entire CDR data set is reprocessed, and the product version number is incremented in the file name as well as in the PRODUCT_VERSION_ID in the label. Finally, the DATASET.CAT files are updated to indicate the changes associated with the new version and the level (% difference) of the change. After ensuring that existing CDR data volume is up to date, the processing software then inquires if new EDRs have arrived at the SOC and, if so, generates the CDR products and delivers them to the SOC. At the SOC, these products are immediately available to the science team for further analysis. Both new and revised MAG CDRs will be merged into the MAG CDR data volume and transmitted to PDS following the delivery schedule described in section 5.3.3.
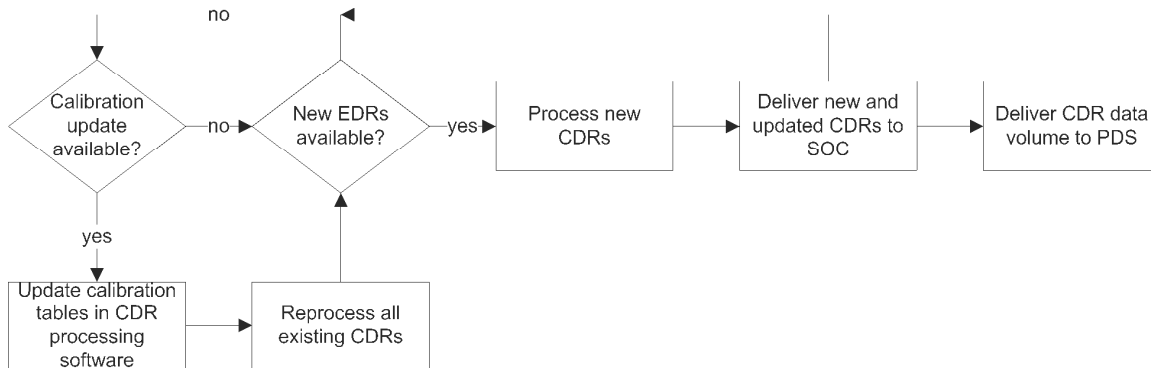
Figure 3: CDR processing flow

The documentation volume is updated whenever the MAG team determines that they have a sufficiently improved calibration to warrant a new release. PDS provides public access to the data products through its online distribution system. The products are used for engineering support, direct science analysis, and construction of other science products.

5.3.3 Data Flow

The MESSENGER SOC operates under the auspices of the MESSENGER Project Scientist to plan data acquisition, generate, and validate data archives. The SOC supports and works with the MOC, the Science Team, instrument scientists, and the PDS. At the SOC, "quick look" plots are generated from the CDR products, which are used by the science and instrument teams to monitor instrument performance. It is expected that the CDR products delivered to PDS will contain the full range of data as specified in this SIS.

The data flow diagram (Figure 2) shows the general flow of data within the MESSENGER project and to the PDS. The MOC handles Level 1 data flow from DSN and the SOC converts the raw telemetry into EDRs, which are subsequently converted into CDRs. The Science Team validates the CDRs. Corrections and changes to the CDRs are implemented by the MAG instrument team. Documentation and CDRs are delivered to the PDS PPI node. All SPICE Kernels used in CDR processing are delivered to the PDS Navigation and Ancillary Information (NAIF) node.

Deep Space Mission Services (DSMS)

Mission Navigation

Planetary Data System (PDS)
Planetary Plasma Interactions (PPI) Node

Commands   **Telemetry**

Documentation
Calibration
EDRs, CDRs
SPICE Kernels
Science Products

Position   **Clock**
Attitude

Telemetry

Science Acquisition

Data Management and Archiving

Mission Operations Center (MOC)

Planning
SPICE
Kernels
Other

Science Planning Group

Science Operations Center (SOC)

Trajectory
Maintenance

EDRs
CDRs

Documentation
Calibration
Science Products
SPICE Kernels

Planning
Goals

Mission Design

Science Team

Figure 4: Data flow.

The MESSENGER SOC will deliver the MAG CDR data volume to the PDS PPI node in standard product packages. Each package, consisting of data and ancillary data files, will be organized by directory structures consistent with the volume design described in section 6.8. The initial release will also contain the documents and required files for the MAG documentation volume, organized by directory structures as described in section 6.7. Subsequent releases to the MAG documentation volume will be at the d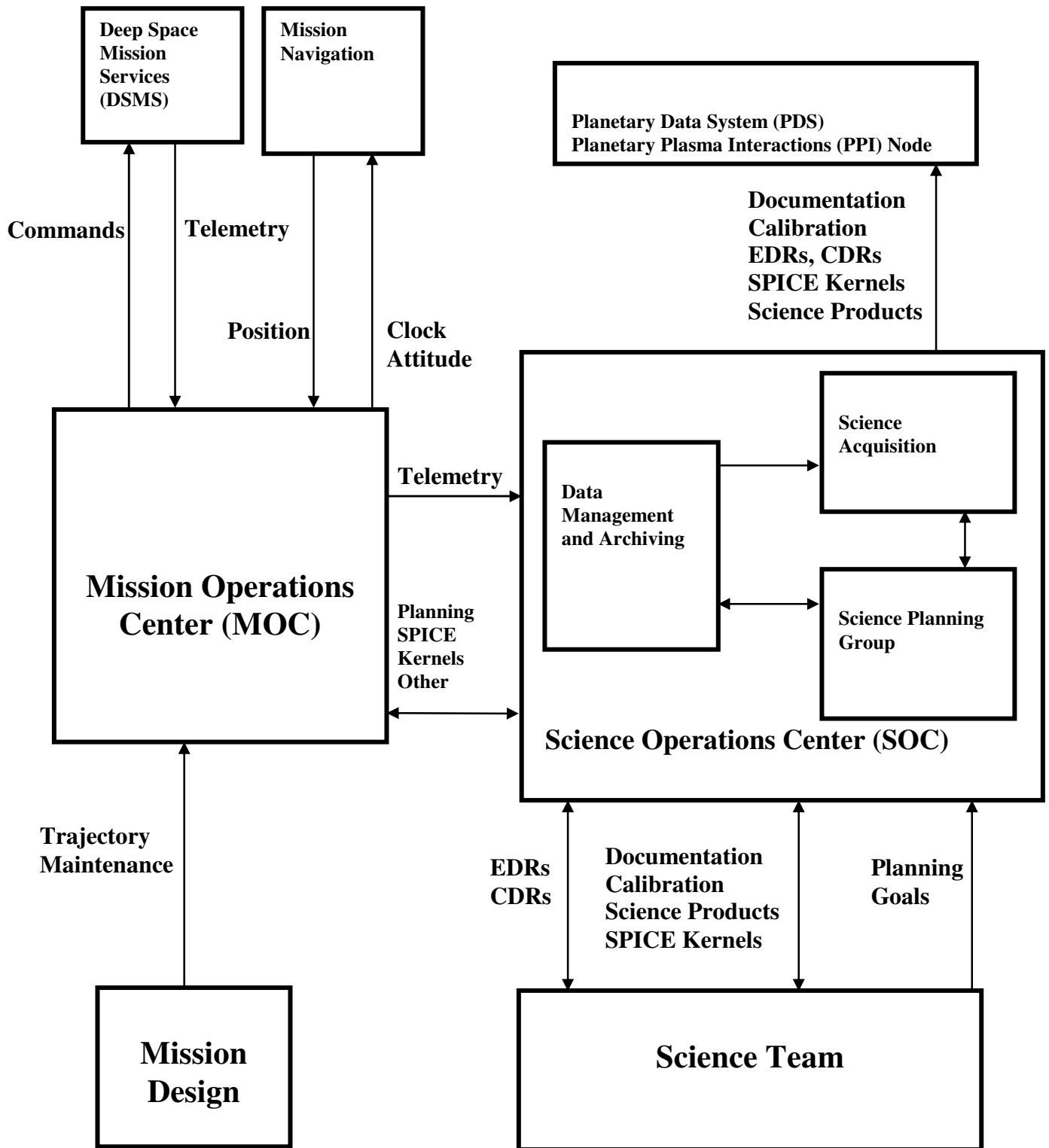iscretion of the MAG team and delivered whenever the MAG team determines that they have a sufficiently improved calibration to warrant a new release.

The following describes the electronic transfer process of releasing data to PDS for both the data volume and the documentation volume. This transfer process will be used for the first PDS delivery. Future data deliveries will be assumed to follow the same process unless otherwise noted in an update of this document. Given the long duration of the mission, the MESSENGER Project Office is reserving the option of exploring alternate data delivery methods for subsequent deliveries. Any changes in the delivery process will be noted in an update to the SIS document specifying the effective dates for the new delivery process. The delivery of products to the data volume will follow the schedule in the MESSENGER Data Management and Archiving Plan. A delivery may include both new data and revisions to previously delivered products associated with calibration updates. The delivery date for updates to the documentation volume will be determined as needed at the discretion of the MAG team.

In the week prior to the delivery date, the directory structure will be compressed into one or multiple zip archives for transmittal to the PDS node. The zip archive preserves the directory structure internally so that it can be recreated after electronic delivery to the PDS node. The zip archive file is transmitted to the PDS node via FTP to an account set up by the receiving node. A checksum file for the archive created using the MD5 algorithm will also be transmitted to provide an independent method of verifying the integrity of the zip file after it has been sent. Within days of transmittal the PDS node will acknowledge receipt of the archive and checksum file. If acknowledgement is not received, or if problems are reported, the MESSENGER SOC will take corrective action to effect re-transmittal.

After transmittal the PDS node will uncompress the zip archive file and check for data integrity using the checksum file. The node will then perform any additional verification and validation of the data and will report any discrepancies or problems to the MESSENGER SOC. It is expected that the node will perform these checks in about two weeks. After inspection has been completed to the satisfaction of the PDS node, the node will issue acknowledgement of successful receipt of the data to the MESSENGER SOC.

Following receipt of a data delivery, the PDS node will organize the data into a PDS volume archive structure in its online data system. When updated products are received by the PDS, previously delivered versions of the files are marked as SUPERCEDED and the latest release is made available online. Superceded versions of the files are maintained by the PDS. Newly delivered data will be publicly available from PDS once accompanying labels and other documentation have been validated.

5.3.4 Labeling and Identification

The label area of the CDR data files conform to the PDS version 3.7 standards. For more information on this standard consult the PDS Standards Reference Document. The purpose of the PDS label is to describe the data and provide ancillary information. The label file is detached and separate from the CDR data file. The data file itself will contain the data in an ASCII table format. There will be one detached PDS label file for every data file. There are four standard CDR data products, described in section 5.2. The DATA_SET_ID for the MAG CDR data volume is MESS-E/V/H/SW-MAG-3-CDR-CALIBRATED-Vx, where Vx represents the release version number. The data products are identified via the PRODUCT_ID keyword and the file naming convention (section 6.2). Example label files for each CDR data product are shown in the Appendix (sections 8.1–8.4). Details about the table structure for each data file are specified in section 6.3.

5.4 Standards Used in Generating Data Products

5.4.1 PDS Standards

The MAG CDR products are constructed according to the data object concepts developed by the PDS. By adopting the PDS format, the MAG CDR products are consistent in content and organization with other planetary data collections. In the PDS standard, the CDR data file is grouped into objects with PDS labels describing each object. Each CDR product consists of two files:

- A data file containing an ASCII table object (the primary data) in fixed-field format. This makes the data easy to read by many commercial off-the-shelf programs.
- A label file which serves as a high-level description of the fields in the data file. The label file also contains the product release notes specifying the data quality and ancillary information that allow exact reconstruction of the EDR-to-CDR conversion.

5.4.2 Time Standards

The time fields in the CDR table objects reference both Coordinated Universal Time (UTC) and the Mission Elapsed Time (MET). The MET is the spacecraft time in seconds that is transmitted to the MESSENGER subsystems by the Integrated Electronics Module (IEM). MET = 0 is August 3, 2004 05:59:16 UTC, which is 1000 seconds prior to MESSENGER launch. Due to relativistic effects, clock drift, and circumstances occurring during the mission, the MET is not a true account of seconds since launch. The SPICE spacecraft clock coefficients file is used to convert between MET and UTC. A description of the conversions including both instrument latency corrections and the required calls using the SPICE toolkit is given in the temporary calibration description MAG_EDR2CDR.PDF.

5.4.3 Data Storage Conventions

The data are organized following PDS standards and stored on hard disk for rapid access during mission operations. The CDR data and labels are stored in ASCII text files, and the lines are terminated by a carriage return/line feed combination. The MESSENGER SOC will transfer data to PDS via electronic transfer and delivery methods as detailed in

section 5.3.3. After verification of the data transfer, PDS will provide public access to MESSENGER science data products through its online data distribution system.

5.5 Data Validation

The final MAG CDR archive volume will include all data acquired during the MESSENGER mission. Before MAG boom deployment the data are corrupted by uncorrectable contamination from near-field spacecraft generated signals. After boom deployment in March 2005, data obtained with the MAG sensor in darkness are corrupted by signals due to a design error in the magnetometer heater control. A software heater control that avoids operation causing this contamination was implemented in stages and fully implemented in March 2007. Periods with correctable and uncorrectable contamination signals are indicated by the data quality flag provided in the release notes.

The initial release of the MAG CDR data volumes will occur during the first CDR delivery date as stated in the MESSENGER Data Management and Archiving Plan. This delivery will be accompanied by an update to the documentation volume. Updates to the data volume will occur according to the schedule in the MESSENGER Data Management and Archiving Plan. Updates to the documentation volume will occur at the discretion of the MAG team.

PDS standards recommend that all data included in the formal archive be validated through a peer-review process. Only those data indicated as free of contamination or containing correctable contamination are subject to validation of the data quality. This process is designed to ensure that both the data and documentation are of sufficient quality to be useful to future generations of scientists. The schedule of PDS data deliveries, however, necessitate some modification of the normal PDS review process since it is impractical to convene a review panel to examine the archive volume for every PDS data delivery. The following describes the modified validation process. The process is presented as several steps, most of which occur in the PDS peer review. This peer review is conducted before any volumes are produced and released to PDS.

The peer review panel consists of members of the MAG team, members of ACT, the PPI node of PDS, and at least one outside scientist actively working in the field of planetary, terrestrial or interplanetary magnetic fields research. The PDS personnel are responsible for validating that the volumes are fully compliant with PDS standards. The instrument team, ACT, and outside reviewer(s) are responsible for verifying the content of the data set, the completeness of the documentation, and the usability of the data in its archive format.

The peer review will validate the documentation and data archive volumes via a two step process. First the panel reviews this document and verifies that the volumes and CDRs produced to this specification constitute a stand-alone data set with sufficient information to allow independent analysis. Next the panel reviews the initial release of the data and documentation volumes to verify that the volumes meet this specification. Once automated production begins, software provided by ACT produce a summary of each data product and software provided by the PPI node verifies that all the files required by

PDS are present and the files themselves conform to PDS standards. If an error is detected by either of the above programs, the error is corrected, if possible, before the update to the volume is delivered. Otherwise the correction will occur at the next scheduled delivery date. If an error in a data file is uncorrectable, (i.e. an error in the downlink data file) this is captured in the data quality indicator and the error is described in the cumulative errata file that is included in the data archive volume.

The peer review will also validate the MAG CDR data in a two step process. The first step consists of reviewing a sample data set for compliance with the PDS standards. The sample data set is delivered and reviewed in conjunction with delivery and review of this SIS document. The second step is examination of the data to ensure usability and completeness. The PDS personnel will be responsible for validating that the CDR data set is fully compliant with PDS standards. The instrument team, ACT, and the outside science reviewer(s) will be responsible for verifying the content of the data set, the completeness of the documentation, and the usability of the data in its archive format.

Any deficiencies in the archive data or documentation volumes will be recorded as liens against the product by the review panel. The sample data set is created using software provided by the MAG team. Once the sample data is validated, and all liens placed against the product or product generation software are resolved, the same software will be used to generate subsequent data products in an automated fashion.

Once automated production begins, the data file content will be spot checked by members of the MAG team. For this purpose, the MAG team provides software to routinely generate "Quick look" products, which are examined by members of the MAG team on a regular basis. In addition, the data will be actively used by team members to perform their analysis. Any discrepancies in the data noted during these activities will be investigated. If the discrepancy is a data error, the response will depend on the source of the error. If the error is in the software producing the data product, the error will be corrected and the data products affected will be reproduced. If there is a correctable error in a data file, the file will be replaced. If an error in a data file is uncorrectable, the error will be identified in the data quality flag and described in the cumulative errata file included in the archive volume. The structure of data files and labels will be spot checked by the PPI node for compliance with PDS standards and this SIS.

6. Detailed Data Product Specifications

6.1 Data Product Structure and Organization

The MESSENGER MAG CDR data set will be archived at the PDS PPI Node as a data archive volume. The CDR data set in the data archive volume is intended to store the data in calibrated form preserving the original time resolution. The automated production and release of the CDRs thereby lends itself to a regular release schedule as shown in the MESSENGER Data Management and Archiving Plan. If errors are discovered, the data will be replaced with corrected CDRs on the next scheduled delivery date.

The calibration parameters and procedures, required to convert EDRs into CDR and RDR products, are archived at the PDS PPI Node in the MAG documentation volume. The MAG documentation volume is referenced by all MAG data archive volumes (EDR, CDR, and RDR), and contains the MAG SIS documents, calibration tables and procedures, and other documents applicable to these data archive volumes. An update to the MAG documentation volume will accompany the initial release of the CDR data archive. The updated release will contain the initial CDR level documentation and the parameters derived from the ground and in-flight calibration tests. After the initial release, there will be updates to the documentation volume whenever the MAG team determines that they have a sufficiently improved calibration to warrant a new release.

6.2 File Naming Conventions

The file names for PDS data volumes are restricted to a maximum 27 character file name and a 3 character extension name with a period separating the file and extension names. For all MAG CDR data files the base form of the CDR filename (without the file extension) is: "MAGCCCRRRYYDDD_V##".

The ASCII table files are defined by the file extension ".TAB" and the detached PDS label file with the file extension ".LBL". The file naming convention of the presently existing four CDR products is as follows.

MAG: Instrument name
CCC: Coordinate system:
       SC_ – MAG sensor and MESSENGER spacecraft
       J2K – J2000
       MSO – Mercury solar orbital
       VSO – Venus solar orbital
       MBF – Mercury body fixed
       RTN – Radial-Tangential-Normal
       CAL – Placeholder for coordinate-system independent calibrated data

RRR: Record type:
      SCI – Science
      LAC – AC

YY: Last two digits of the year in which the data were acquired.
DDD: Three-digit day of year in which the data where acquired.

V##: Two-digit version number. The initial version number is "V01". The version number increments to "V02", "V03", etc., for each successive version of the CDR product that is produced. A new version of the CDR product may be produced as a result of an error in the product or as a result of errors discovered in the product generation process.

6.3 Data Format Description

The MAG CDR data are stored in ASCII table format. A detached PDS label file will provide a detailed description of the structure of the ASCII table and the product release

notes. The release notes contain the data quality assessment and ancillary information that allow exact reconstruction of the EDR-to-CDR conversion. The following tables present the structure of the data tables in a user-friendly format. The fields are numbered according to their column order in the table. Data_Type refers to the PDS standards data type for a particular column in the table.

6.3.1 MAG SC Coordinates Science CDR ASCII Table

The file naming convention for these products is MAGSC_RRRYYDDD_V## as defined in section 6.2. The columns contain the following data:

1. **YEAR**
   Bytes: 4   Data_Type: ASCII_INTEGER

   UTC year associated with the magnetic field samples Bx, By, Bz in each record.

2. **DAY_OF_YEAR**
   Bytes: 3   Data_Type: ASCII_INTEGER

   UTC day of year associated with the magnetic field samples Bx, By, Bz in each record.

3. **HOUR**
   Bytes: 2   Data_Type: ASCII_INTEGER

   UTC hour associated with the magnetic field samples Bx, By, Bz in each record.

4. **MINUTE**
   Bytes: 2   Data_Type: ASCII_INTEGER

   UTC minute associated with the magnetic field samples Bx, By, Bz in each record.

5. **SECOND**
   Bytes: 6   Data_Type: ASCII_REAL

   UTC second associated with the magnetic field samples Bx, By, Bz in each record.

6. **TIME_TAG**
   Bytes: 13   Data_Type: ASCII_REAL

   A derived value for the timetag associated with the x,y,z sample in each record. The derived value is created by the following formula:
   MET + 0.05 * delta_ts + (dt_sample)*(I-1) - latency.
   MET is the mission elapsed time for the entire science packet.
   delta_ts is the delta time in seconds between the MET and the first sample in the downloaded science packet.
   dt_sample is the time between samples in seconds and given by
   dt_sample = 1/sample_rate where sample_rate is the reported sample rate in samples per second.
   I is the incremental counter for each data sample in the science packet. I=1 is the first sample in the packet.
   Latency is the sample rate-dependent delay of the time stamp recording relative to the actual time of observation.

7. **ACTUAL_RANGE**

Bytes: 1   Data_Type: ASCII_INTEGER

Actual measurement range used by MAG: =0 (1530 nT full scale), =1 (51300 nT full scale).

8. **SAMPLE_RATE**
   Bytes: 5   Data_Type: ASCII_REAL

   Sample rate used by MAG in units of samples per second.

9. **BX_SENSOR**
   Bytes: 10   Data_Type: ASCII_REAL

   X axis magnetic field value in sensor coordinates in units of nano-Tesla.

10. **BY_SENSOR**
    Bytes: 10   Data_Type: ASCII_REAL

    Y axis magnetic field value in sensor coordinates in units of nano-Tesla.

11. **BZ_SENSOR**
    Bytes: 10   Data_Type: ASCII_REAL

    Z axis magnetic field value in sensor coordinates in units of nano-Tesla.

12. **BX_SPACECRAFT**
    Bytes: 10   Data_Type: ASCII_REAL

    X axis magnetic field value in spacecraft coordinates in units of nano-Tesla.

13. **BY_SPACECRAFT**
    Bytes: 10   Data_Type: ASCII_REAL

    Y axis magnetic field value in spacecraft coordinates in units of nano-Tesla.

14. **BZ_SPACECRAFT**
    Bytes: 10   Data_Type: ASCII_REAL

    Z axis magnetic field value in spacecraft coordinates in units of nano-Tesla.

6.3.2 MAG J2000 Coordinates Science CDR ASCII Table

The file naming convention for these products is MAGJ2KRRRYYDDD_V## as defined in section 6.2. The columns contain the following data:

1. **YEAR**
   Bytes: 4   Data_Type: ASCII_INTEGER

   UTC year associated with the magnetic field samples Bx, By, Bz in each record.

2. **DAY_OF_YEAR**
   Bytes: 3   Data_Type: ASCII_INTEGER

   UTC day of year associated with the magnetic field samples Bx, By, Bz in each record.

3. **HOUR**
   Bytes: 2   Data_Type: ASCII_INTEGER

UTC hour associated with the magnetic field samples Bx, By, Bz in each record.

4. **MINUTE**
   Bytes: 2   Data_Type: ASCII_INTEGER

UTC minute associated with the magnetic field samples Bx, By, Bz in each record.

5. **SECOND**
   Bytes: 6   Data_Type: ASCII_REAL

UTC second associated with the magnetic field samples Bx, By, Bz in each record.

6. **TIME_TAG**
   Bytes: 13   Data_Type: ASCII_REAL

A derived value for the timetag associated with the x,y,z sample in each record. The derived value is created by the following formula:
MET + 0.05 * delta_ts + (dt_sample)*(I-1) - latency.
MET is the mission elapsed time for the entire science packet.
delta_ts is the delta time in seconds between the MET and the first sample in the downloaded science packet.
dt_sample is the time between samples in seconds and given by
dt_sample = 1/sample_rate where sample_rate is the reported sample rate in samples per second.
I is the incremental counter for each data sample in the science packet. I=1 is the first sample in the packet.
Latency is the sample rate-dependent delay of the time stamp recording relative to the actual time of observation.

7. **X_J2000**
   Bytes: 14   Data_Type: ASCII_REAL

X position in J2000 coordinates in units of kilometers.

8. **Y_J2000**
   Bytes: 14   Data_Type: ASCII_REAL

Y position in J2000 coordinates in units of kilometers.

9. **Z_J2000**
   Bytes: 14   Data_Type: ASCII_REAL

Z position in J2000 coordinates in units of kilometers.

10. **BX_J2000**
    Bytes: 10   Data_Type: ASCII_REAL

X axis magnetic field value in J2000 coordinates in units of nano-Tesla.

11. **BY_J2000**
    Bytes: 10   Data_Type: ASCII_REAL

Y axis magnetic field value in J2000 coordinates in units of nano-Tesla.

12. **BZ_J2000**

Bytes: 10   Data_Type: ASCII_REAL

Z axis magnetic field value in J2000 coordinates in units of nano-Tesla.

6.3.3 MAG Mercury Solar Orbital (MSO) Coordinates Science CDR ASCII Table

The file naming convention for these products is MAGMSORRRYYDDD_V## as defined in section 6.2. The columns contain the following data:

1. **YEAR**
   Bytes: 4   Data_Type: ASCII_INTEGER

   UTC year associated with the magnetic field samples Bx, By, Bz in each record.

2. **DAY_OF_YEAR**
   Bytes: 3   Data_Type: ASCII_INTEGER

   UTC day of year associated with the magnetic field samples Bx, By, Bz in each record.

3. **HOUR**
   Bytes: 2   Data_Type: ASCII_INTEGER

   UTC hour associated with the magnetic field samples Bx, By, Bz in each record.

4. **MINUTE**
   Bytes: 2   Data_Type: ASCII_INTEGER

   UTC minute associated with the magnetic field samples Bx, By, Bz in each record.

5. **SECOND**
   Bytes: 6   Data_Type: ASCII_REAL

   UTC second associated with the magnetic field samples Bx, By, Bz in each record.

6. **TIME_TAG**
   Bytes: 13   Data_Type: ASCII_REAL

   A derived value for the timetag associated with the x,y,z sample in each record. The derived value is created by the following formula:
   MET + 0.05 * delta_ts + (dt_sample)*(I-1) - latency.
   MET is the mission elapsed time for the entire science packet.
   delta_ts is the delta time in seconds between the MET and the first sample in the downloaded science packet.
   dt_sample is the time between samples in seconds and given by
   dt_sample = 1/sample_rate where sample_rate is the reported sample rate in samples per second.
   I is the incremental counter for each data sample in the science packet. I=1 is the first sample in the packet.
   Latency is the sample rate-dependent delay of the time stamp recording relative to the actual time of observation.

7. **X_MSO**
   Bytes: 14   Data_Type: ASCII_REAL

   X position in Mercury solar orbital (MSO) coordinates in units of kilometers.

8. **Y_MSO**

Bytes: 14   Data_Type: ASCII_REAL

Y position in Mercury solar orbital (MSO) coordinates in units of kilometers.

9. **Z_MSO**
Bytes: 14   Data_Type: ASCII_REAL

Z position in Mercury solar orbital (MSO) coordinates in units of kilometers.

10. **BX_MSO**
Bytes: 10   Data_Type: ASCII_REAL

X axis magnetic field value in Mercury solar orbital (MSO) coordinates in units of nano-Tesla.

11. **BY_MSO**
Bytes: 10   Data_Type: ASCII_REAL

Y axis magnetic field value in Mercury solar orbital (MSO) coordinates in units of nano-Tesla.

12. **BZ_MSO**
Bytes: 10   Data_Type: ASCII_REAL

Z axis magnetic field value in Mercury solar orbital (MSO) coordinates in units of nano-Tesla.

For the second Venus flyby, science data are similarly provided in Venus Solar Orbital (VSO) coordinates. Accordingly, the file naming convention for these products is MAGVSORRRYYDDD_V## as defined in section 6.2. The column format for these data products is identical to those provided for MSO coordinates, only that the center of reference is Venus rather than Mercury.

6.3.4 MAG Mercury Body-fixed (MBF) Coordinates Science CDR ASCII Table

The file naming convention for these products is MAGMBFRRRYYDDD_V## as defined in section 6.2. The columns contain the following data:

1. **YEAR**
Bytes: 4   Data_Type: ASCII_INTEGER

UTC year associated with the magnetic field samples Bx, By, Bz in each record.

2. **DAY_OF_YEAR**
Bytes: 3   Data_Type: ASCII_INTEGER

UTC day of year associated with the magnetic field samples Bx, By, Bz in each record.

3. **HOUR**
Bytes: 2   Data_Type: ASCII_INTEGER

UTC hour associated with the magnetic field samples Bx, By, Bz in each record.

4. **MINUTE**
Bytes: 2   Data_Type: ASCII_INTEGER

UTC minute associated with the magnetic field samples Bx, By, Bz in each record.

5. **SECOND**
   Bytes: 6   Data_Type: ASCII_REAL

   UTC second associated with the magnetic field samples Bx, By, Bz in each record.

6. **TIME_TAG**
   Bytes: 13   Data_Type: ASCII_REAL

   A derived value for the timetag associated with the x,y,z sample in each record. The derived value is created by the following formula:
   MET + 0.05 * delta_ts + (dt_sample)*(I-1) - latency.
   MET is the mission elapsed time for the entire science packet.
   delta_ts is the delta time in seconds between the MET and the first sample in the downloaded science packet.
   dt_sample is the time between samples in seconds and given by
   dt_sample = 1/sample_rate where sample_rate is the reported sample rate in samples per second.
   I is the incremental counter for each data sample in the science packet. I=1 is the first sample in the packet.
   Latency is the sample rate-dependent delay of the time stamp recording relative to the actual time of observation.

7. **X_MBF**
   Bytes: 14   Data_Type: ASCII_REAL

   X position in Mercury body-fixed (MBF) coordinates in units of kilometers.

8. **Y_MBF**
   Bytes: 14   Data_Type: ASCII_REAL

   Y position in Mercury body-fixed (MBF) coordinates in units of kilometers.

9. **Z_MBF**
   Bytes: 14   Data_Type: ASCII_REAL

   Z position in Mercury body-fixed (MBF) coordinates in units of kilometers.

10. **BX_MBF**
    Bytes: 10   Data_Type: ASCII_REAL

    X axis magnetic field value in Mercury body-fixed (MBF) coordinates in units of nano-Tesla.

11. **BY_MBF**
    Bytes: 10   Data_Type: ASCII_REAL

    Y axis magnetic field value in Mercury body-fixed (MBF) coordinates in units of nano-Tesla.

12. **BZ_MBF**
    Bytes: 10   Data_Type: ASCII_REAL

    Z axis magnetic field value in Mercury body-fixed (MBF) coordinates in units of nano-Tesla.

6.3.5 MAG Radial-Tangential-Normal (RTN) Coordinates Science CDR ASCII Table

The file naming convention for these products is MAGRTNRRRYYDDD_V## as defined in section 6.2. The columns contain the following data:

1. **YEAR**
   Bytes: 4   Data_Type: ASCII_INTEGER

   UTC year associated with the magnetic field samples Bx, By, Bz in each record.

2. **DAY_OF_YEAR**
   Bytes: 3   Data_Type: ASCII_INTEGER

   UTC day of year associated with the magnetic field samples Bx, By, Bz in each record.

3. **HOUR**
   Bytes: 2   Data_Type: ASCII_INTEGER

   UTC hour associated with the magnetic field samples Bx, By, Bz in each record.

4. **MINUTE**
   Bytes: 2   Data_Type: ASCII_INTEGER

   UTC minute associated with the magnetic field samples Bx, By, Bz in each record.

5. **SECOND**
   Bytes: 6   Data_Type: ASCII_REAL

   UTC second associated with the magnetic field samples Bx, By, Bz in each record.

6. **TIME_TAG**
   Bytes: 13   Data_Type: ASCII_REAL

   A derived value for the timetag associated with the x,y,z sample in each record. The derived value is created by the following formula:
   MET + 0.05 * delta_ts + (dt_sample)*(I-1) - latency.
   MET is the mission elapsed time for the entire science packet.
   delta_ts is the delta time in seconds between the MET and the first sample in the downloaded science packet.
   dt_sample is the time between samples in seconds and given by
   dt_sample = 1/sample_rate where sample_rate is the reported sample rate in samples per second.
   I is the incremental counter for each data sample in the science packet. I=1 is the first sample in the packet.
   Latency is the sample rate-dependent delay of the time stamp recording relative to the actual time of observation.

7. **RDIST**
   Bytes: 14   Data_Type: ASCII_REAL

   Radial distance of the MESSENGER spacecraft from the Sun in units of kilometers.

8. **LATITUDE_ECLIP**
   Bytes: 12   Data_Type: ASCII_REAL

24

Northward latitude of the MESSENGER spacecraft above instantaneous ecliptic plane in units of degrees.

9. **AZIMUTH_ECLIP**
   Bytes: 12   Data_Type: ASCII_REAL

   Azimuth angle of the MESSENGER spacecraft in the instantaneous ecliptic plane with respect to the Earth-Sun line in units of degrees, positive in direction of the Earth's orbital motion.

10. **BR**
    Bytes: 10   Data_Type: ASCII_REAL

    Magnetic field value in units of nano-Tesla in Sun-to-spacecraft direction.

11. **BT**
    Bytes: 10   Data_Type: ASCII_REAL

    Magnetic field value in units of nano-Tesla in the tangential direction given by the cross product of the Sun spin axis and the Sun-to-spacecraft vector.

12. **BN**
    Bytes: 10   Data_Type: ASCII_REAL

    Magnetic field value in units of nano-Tesla in direction of the cross product of the Sun-to-spacecraft vector and the tangential direction.

6.3.6 MAG AC CDR ASCII Table

The file naming convention for these products is MAGCALLACYYDDD_V## as defined in section 6.2. The columns contain the following data:

1. **YEAR**
   Bytes: 4   Data_Type: ASCII_INTEGER

   UTC year associated with the logAC sample in each record.

2. **DAY_OF_YEAR**
   Bytes: 3   Data_Type: ASCII_INTEGER

   UTC day of year associated with the logAC sample in each record.

3. **HOUR**
   Bytes: 2   Data_Type: ASCII_INTEGER

   UTC hour associated with the logAC sample in each record.

4. **MINUTE**
   Bytes: 2   Data_Type: ASCII_INTEGER

   UTC minute associated with the logAC sample in each record.

5. **SECOND**
   Bytes: 6   Data_Type: ASCII_REAL

UTC second associated with the logAC sample in each record.

6. **TIME_TAG**
   Bytes: 13   Data_Type: ASCII_REAL

   A derived value for the timetag associated with the logAC sample in each record. The derived value is created by the following formula:
   MET + 0.05 * delta_ts + (dt_sample)*(I-1) - latency.
   MET is the mission elapsed time for the entire science packet.
   delta_ts is the delta time in seconds between the MET and the first sample in the downloaded science packet.
   dt_sample is the time between samples in seconds and given by
   dt_sample = 1/sample_rate where sample_rate is the reported sample rate in samples per second.
   I is the incremental counter for each data sample in the science packet. I=1 is the first sample in the packet.
   Latency is the sample rate-dependent delay of the time stamp recording relative to the actual time of observation.

7. **AC_AXIS**
   Bytes: 1   Data_Type: ASCII_INTEGER

   Selected AC axis: X=0, Y=1, Z=2.

8. **B_AC**
   Bytes: 10   Data_Type: ASCII_REAL

   Average output amplitude in units of nano-Tesla of a 1-to-10 Hz bandpass filter for the selected magnetometer axis selected by command.

6.4 Label and Header Descriptions

The following are the keyword definitions for the detached PDS label file accompanying the ASCII data file. The detached PDS label file has the same name as the data file it describes, except for the extension .LBL to distinguish it as a label file.

PDS_VERSION_ID
    Represents the version number of the PDS standards documents that is valid when a data product label is created. PDS3 is used for the MESSENGER data products.

FILE_RECORDS
    Indicates the number of physical file records, including both label records and data records.

RECORD_TYPE
    Indicates the record format of a file. Note: In the PDS, when record_type is used in a detached label file it always describes its corresponding detached data file, not the label file itself. The use of record_type along with other file-related data elements is fully described in the PDS Standards Reference.

RECORD_BYTES
    Indicates the number of bytes in a physical file record, including record terminators and separators. Note: In the PDS,

the use of record_bytes, along with other file-related data
elements is fully described in the Standards Reference.

PRODUCT_ID
Represents a permanent, unique identifier assigned to a data
product by its producer. For the MAG CDRs it is the base file
naming convention (section 6.2) without the file extensions.

SOURCE_PRODUCT_ID
Represents the unique identifier of the EDR data product that was
the source data for the CDR product.

PRODUCT_VERSION_ID
Defines the version of the CDR product. Version numbering starts
at "V1" and will be incremented if the CDR product needs to be
regenerated due to errors in the product or the software creating
the product.

PRODUCT_CREATION_TIME
Defines the UTC system format time when a product was created.

PRODUCT_TYPE
Identifies the type or category of a product within a data set.

STANDARD_DATA_PRODUCT_ID
Used to link a MAG CDR file to one of the four types of MAG data
products defined within the MAG CDR SIS.

SOFTWARE_NAME
Identifies the data processing software used to convert from EDR
into CDR products.

SOFTWARE_VERSION_ID
Identifies the version of the data processing software used to
generate the CDR products from the EDR products.

INSTRUMENT_HOST_NAME
Specifies the host on which the MAG instrument is based, the
MESSENGER spacecraft.

INSTRUMENT_NAME
Provides the full name of the MAG instrument.

INSTRUMENT_ID
Provides an abbreviated name or acronym which identifies an
instrument.

DATA_SET_ID
The data_set_id element is a unique alphanumeric identifier for a
data set or a data product. There is only 1 data_set_id for the
MAG CDRs.

MISSION_PHASE_NAME
Provides the commonly used identifier of a mission phase.

TARGET_NAME

The target_name element identifies a target. The target may be a planet, satellite,ring,region, feature, asteroid or comet.

START_TIME
Provides the date and time of the beginning of an event or observation in UTC system format.

STOP_TIME
Provides the date and time of the end of an observation or event in UTC system format.

SPACECRAFT_CLOCK_START_COUNT
Provides the value of the spacecraft clock at the beginning of a time period of interest.

SPACECRAFT_CLOCK_STOP_COUNT
Provides the value of the spacecraft clock at the end of a time period of interest.

^TABLE
This is a pointer to the external data file containing the ASCII table. The TABLE object is a uniform collection of rows containing ASCII values stored in columns. The TABLE content is identified in the DESCRIPTION field and the release notes, described in section 6.5, are captured in the NOTE field.

6.5 Release Notes

Table 1: MAG data quality flag definitions.

S: Sensor Configuration	Definition
0	Sensor stowed – prior to boom deployment
1	Boom deployed – SC +Y axis to Sun - sensor in sunlight
2	Boom deployed – SC –Y axis to Sun - sensor in shadow

H: Heater Mode	Definition
0	Hardware regulation (MAG FSW V8)
1	Software regulation version 1 (MAG FSW V9)
2	Software regulation version 2 (MAG FSW V10)

C: Contamination	Definition

0	No contamination signals known to be present
1	Uncorrectable contamination signals present
2	Contamination signals present but correctable

The purpose of the release notes is twofold. First, the release notes contain the data quality assessment, represented by a three-digit code, denoted SHC, which is defined in Table 1. S indicates the configuration of the sensor. H indicates the sensor survival heater control mode being used. C indicates the presence of contamination in the data and whether contamination, if present, is judged to be correctable to meet the science requirement of 1 nT. Second, the release notes contain ancillary information that allows accurate reconstruction of the generation of CDR products from EDR-level data. This includes the magnetometer offsets, which are updated from in-flight data analysis on a regular basis, and the SPICE kernels used for deriving UTC time and spacecraft position and orientation.

6.6 Archive Volume and File Size

In addition to the existing MAG EDR data and documentation volumes, a new archive volume is created to hold the MAG CDR data. This archive volume will contain the CDR data and required files for conforming to PDS volume archive standards. This includes the Index files, AAREADME.TXT, etc. This is designated as the MAG CDR data archive volume. The data volume can be estimated from the number of bytes per record and the sample rate. Lower and upper limits for the data volume per day as well as the typical volume for on-orbit operation are given in Table 2. The data volume of the science data depends on the commanded sample rate. For the lower limit, a sample rate of one sample per second is assume, which is the lowest sample rate anticipated for operation in cruise and orbital phase. The upper limit is given by the magnetometer's maximum sample rate of 20 samples per second. For the typical data volume, it is

Table 2: MAG CDR daily data volume estimates.

CDR Product	Record Bytes	Minimum [MB]	Maximum [MB]	Typical [MB]
MAGSC_SCI	111	9.1	182.9	15.7
MAGJ2KSCI	115	9.5	189.5	16.2
MAGMSOSCI	115	9.5	189.5	16.2
MAGVSOSCI	115	9.5	189.5	16.2
MAGMBFSCI	115	9.5	189.5	16.2
MAGRTNSCI	99	8.2	163.1	14.0
MAGCALLAC	50	4.1	4.1	4.1

assumed that data are recorded at 20, 5, and 2 samples for second for 2400, 4000, and 80000 second periods, respectively. The data volume estimate for the AC data are based on a constant sample rate of one sample per second.

The MAG documentation volume will be updated with the documentation required to analyze the CDRs. Ultimately, the MAG documentation volume will contain products related to the MAG EDR, CDR, and RDR data archives. The EDR level of documentation volume has been delivered previously. This release of the documentation

volume will add the CDR level documentation. RDR level documentation will be added to the volume at the time of initial release of that dataset. Once all of the MAG data products are designed and released, the documentation volume will contain the following products:

1. All required PDS catalog files for the EDR, CDR, and RDR archives (dataset, instrument, mission, etc.).
2. The EDR, CDR, and RDR SIS documents.
3. The SSR instrument paper once copyright permission is obtained. This may not be included in the initial release for copyright reasons.
4. The MAG calibration report.
5. A MAG calibration procedures document. This will contain appropriate pseudo-code for calibrating the data, converting the time word (MET to UTC), and transforming the data into useful coordinate systems.
6. Calibration tables including: sensor offsets time series, gains for each gain state, and the matrices required to orthogonalize the field vector components and orient them in the spacecraft frame.
7. Other documents considered useful by the MESSENGER project or MAG team (i.e. "data processing guide").

6.7 Directory Structure and Contents for the MAG Documentation Volume

The following illustration shows the directory structure overview for the MAG documentation volume. This volume will be periodically updated as knowledge of the instrument, its calibration, and its operation improves over time. An update of this volume that includes the calibration procedure including parameters derived from the ground and in-flight calibration tests will accompany the initial release of the CDR data archive. Additional updates will occur whenever the MAG team determines that they have a sufficiently improved calibration to warrant a new release.

Documentation Volume Directory Structure

```
                                          <ROOT>
_____|_____
       |                           |                                        |
<CALIBRATION>                  <CATALOG>                                <DOCUMENT>
                                                                             |
        _____|
       |         |         |                          |                      |
<EDR_SIS>   |   <INSTRUMENT_PAPER> <CALIBRATION_PROCEDURE>   <CALIBRATION_REPORT>
            |
        <CDR_SIS>
```
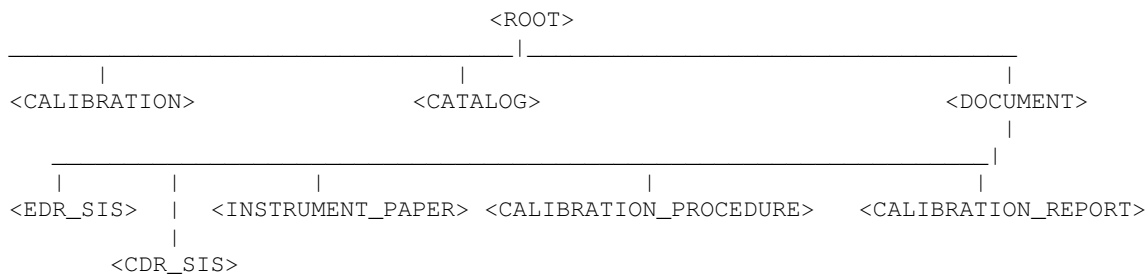
6.7.1 Directory Contents

<ROOT> Directory

```
This is the top-level volume directory. The following are files
contained in the root directory.
```

AAREADME.TXT – This general information file provides users with an overview of the contents and organization of the associated volume, general instructions for its use, and contact information.

VOLDESC.CAT – PDS file containing the VOLUME object giving a high-level description of the contents of the volume. Information includes: production date, producer name and institution, volume ID, etc.

ERRATA.TXT – Text file for identifying and describing errors and/or anomalies found in the current volume, and possibly previous volumes of a set. Any known errors for the associated volume will be documented in this file.

<CALIBRATION> Directory

This will contain the calibration tables needed to analyze the MAG EDR data. The calibration tables are in ASCII comma separated value format.

CALINFO.TXT – This is a brief description of the directory contents and naming conventions.

<CATALOG> Directory

This subdirectory contains the catalog object files for the entire volume. The following files are included in the catalog subdirectory.

CATINFO.TXT: Identifies and describes the function of each file in the catalog directory.

DATASET.CAT: Describes the general content of the data set and includes information about the duration of the mission and the person or group responsible for producing the data.

INSTRUMENT.CAT: Describes physical attributes of the MAG instrument and provides relevant references to published literature.

INSTRUMENT_HOST.CAT: Describes the MESSENGER spacecraft.

MISSION.CAT: Describes the scientific goals and objectives of the MESSENGER program. It also identifies key people and institutions.

PERSON.CAT: Lists and provides contact information for the people involved in the MESSENGER mission, including those involved with MAG.

REF.CAT: Provides references to scientific papers and other publications of interest to those using the data, both for MAG and the mission as a whole.

< DOCUMENT > Directory

This subdirectory contains the documentation that will be needed to understand and analyze the EDR, CDR, and RDR data volumes. The documents will be separated into individual subdirectories according to the document type. The document types are not restricted to the four shown in the graphical depiction of the directory structure. There will be as many document types as needed to categorize each document. The following file is included in the subdirectory.

DOCINFO.TXT: Identifies and describes the function of each file in the DOCUMENT directory.

6.8 Directory Structure and Contents for MAG CDR Data Volume

The following illustration shows the directory structure overview for the MAG data volume. This volume contains the MAG CDR products and any additional files required for the volume to be compliant with PDS volume standards. The content of the volume is expected to remain fairly static except for periodic releases according to the schedule in the MESSENGER Data Management and Archiving Plan. Revised CDRs (if needed) will be delivered according to the same schedule. Revised CDRs will be identified with an updated version number in the filename according to the file naming convention in section 6.2.

Data Volume Directory Structure

```
                                            <ROOT>
_____|_____
     |                        |                          |
 <DATA>                  <GEOMETRY>              <INDEX>
     |
   _|_____
       |                                                            |
 <SCIENCE_DATA>                                            <LOGAC_DATA>
       |                                                        |
    ___|_____             _____|_____
    |      |      |      |             |                 |        |         |
 <J2000> <MBF> <MSO>  <RTN>   <SPACECRAFT>            <2004>   <2005>   <2006> …
                 |                                        |        |         |
      _____|_____                            <JAN>    <FEB>    <MAR> …
      |         |         |
  <2004>    <2005>   <2006> …
                |_____
                |       |       |
             <JAN>   <FEB>   <MAR> …
```
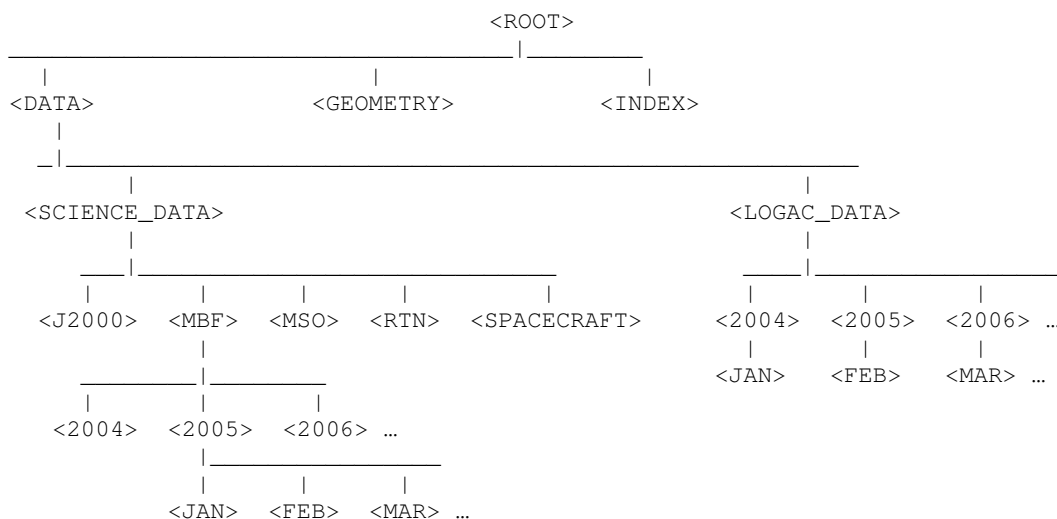
6.8.1 Directory Contents

<ROOT> Directory

This is the top-level directory of the data volume. The following are files contained in the root directory.

AAREADME.TXT – This general information file provides users with an overview of the contents and organization of the associated volume, general instructions for its use, and contact information.

VOLDESC.CAT – This PDS file contains the VOLUME object and gives a high-level description of the contents of the volume. Information includes: production date, producer name and institution, volume ID, etc.

ERRATA.TXT – Text file for identifying and describing errors and/or anomalies found in the current volume, and possibly previous volumes of a set. Any known errors for the associated volume will be documented in this file. This includes revised CDRs meant to replace CDRs in a previous PDS delivery.

<DATA> Directory

This top level directory contains the CDR data products. Directly underneath the <DATA> directory are subdirectories corresponding to the standard data products (section 5.2). The directories are further subdivided by COORDINATE SYSTEM, YEAR, and MONTH directories as applicable. The coordinate systems are abbreviated as noted in section 5.2.

<GEOMETRY> Directory

This subdirectory contains information about the files (e.g. SPICE kernels, etc) needed to determine the observation geometry for the data.

GEOMETRY.TXT : Identifies and describes the SPICE kernels that a user must have in order to determine observation geometry for the data. The SPICE kernel files are archived with the PDS NAIF node.

<INDEX> Directory

This subdirectory contains the indices for all data products on the volume. The following files are contained in the index subdirectory.

INDXINFO.TXT – Identifies and describes the function of each file in the index subdirectory. This includes a description of the structure and contents of each index table in the subdirectory AND usage notes.

INDEX.TAB – The EDR index file is organized as a table. There is one entry for each of the data files included in the MAG data set.

      INDEX.LBL – Detached PDS label for INDEX.TAB.

6.9 Error Handling

The possibility exists that errors may be discovered in the archive even with validation procedures applied to the archive volumes. Errors in the data files may be discovered as detailed in section 5.5. An ERRATA report file is maintained to track and document all discovered uncorrectable errors that may occur during the mission. Correctable errors, such as revised CDRs or CDRs that were missing from a previous PDS delivery will be provided at the next scheduled PDS delivery or at the final delivery date (schedule in the MESSENGER Data Management and Archiving Plan). PDS will then replace the outdated files with the revised CDR files in the data directories of the archive volume. The ERRATA report file is archived in the ROOT directory of the MAG documentation volume.

7. Archive Release Schedule to PDS

The MESSENGER MAG data archives will be transferred from the SOC to the PDS PPI Node using the electronic transfer process detailed in section 5.3.3. The transfer will take place according to the schedule in the MESSENGER Data Management and Archiving Plan.

Table 3: Schedule of Data Releases by Mission Phase - REMOVED – see schedule in MESSENGER Data Management and Archiving Plan.

8. Appendices

8.1 Appendix – MAG SC Coordinates Science CDR PDS Label

```
PDS_VERSION_ID              = PDS3

/*** FILE FORMAT ***/
RECORD_TYPE                 = FIXED_LENGTH
RECORD_BYTES                = 111
FILE_RECORDS                = <file_records>
^TABLE                      = "<file_name>"

/*** GENERAL DATA DESCRIPTION PARAMETERS ***/
DATA_SET_ID                 = "MESS-E/V/H/SW-MAG-3-CDR-CALIBRATED-V1.0"
INSTRUMENT_HOST_NAME        = "MESSENGER"
INSTRUMENT_NAME             = "MAGNETOMETER"
INSTRUMENT_ID               = "MAG"
PRODUCT_ID                  = <product_id>
SOURCE_PRODUCT_ID           = <source_product_id>
PRODUCT_VERSION_ID          = "<product_version_id>"
PRODUCT_CREATION_TIME       = <product_creation_time>
PRODUCT_TYPE                = "CDR"
STANDARD_DATA_PRODUCT_ID    = "MAGSC_SCI"
SOFTWARE_NAME               = "MSGR_MAG_EDR2CDR"
SOFTWARE_VERSION_ID         = "1.0"

MISSION_PHASE_NAME          = "<mission_phase_name>"
TARGET_NAME                 = "<target_name>"
START_TIME                  = <start_time>
STOP_TIME                   = <stop_time>
SPACECRAFT_CLOCK_START_COUNT = <spacecraft_clock_start_time>
SPACECRAFT_CLOCK_STOP_COUNT  = <spacecraft_clock_start_time>
```

```
OBJECT                       = TABLE
 COLUMNS                     = 14
 INTERCHANGE_FORMAT          = ASCII
 ROW_BYTES                   = 111
 ROWS                        = <rows>
 DESCRIPTION                 = "
   The table contains the timetags and 3-axis calibrated samples of the magnetic
   field in sensor and spacecraft coordinates in units of nano-Tesla. The sampling
   rate is commandable and can vary. The table contains data from MAG science
   packets generated on a given day; data from each packet will be stored as one
   row in the ASCII table. START_TIME and STOP_TIME correspond to the TIME_TAG
   values of the first row and last row (respectively) in the table."

 OBJECT                      = COLUMN
  NAME                       = YEAR
  COLUMN_NUMBER              = 1
  START_BYTE                 = 1
  BYTES                      = 4
  DATA_TYPE                  = ASCII_INTEGER
  FORMAT                     = "I4"
  DESCRIPTION                = "Year associated with the magnetic field samples
         Bx, By, Bz in each record."
 END_OBJECT = COLUMN

 OBJECT                      = COLUMN
  NAME                       = DAY_OF_YEAR
  COLUMN_NUMBER              = 2
  START_BYTE                 = 6
  BYTES                      = 3
  DATA_TYPE                  = ASCII_INTEGER
  FORMAT                     = "I3"
  DESCRIPTION                = "Day of year associated with the magnetic field samples
         Bx, By, Bz in each record."
 END_OBJECT = COLUMN

 OBJECT                      = COLUMN
  NAME                       = HOUR
  COLUMN_NUMBER              = 3
  START_BYTE                 = 10
  BYTES                      = 2
  DATA_TYPE                  = ASCII_INTEGER
  FORMAT                     = "I2"
  DESCRIPTION                = "Hour associated with the magnetic field samples
         Bx, By, Bz in each record."
 END_OBJECT = COLUMN

 OBJECT                      = COLUMN
  NAME                       = MINUTE
  COLUMN_NUMBER              = 4
  START_BYTE                 = 13
  BYTES                      = 2
  DATA_TYPE                  = ASCII_INTEGER
  FORMAT                     = "I2"
  DESCRIPTION                = "Minute associated with the magnetic field samples
         Bx, By, Bz in each record."
 END_OBJECT = COLUMN

 OBJECT                      = COLUMN
  NAME                       = SECOND
  COLUMN_NUMBER              = 5
  START_BYTE                 = 16
  BYTES                      = 6
  DATA_TYPE                  = ASCII_REAL
  FORMAT                     = "F6.3"
  DESCRIPTION                = "Second associated with the magnetic field samples
         Bx, By, Bz in each record."
 END_OBJECT = COLUMN

 OBJECT                      = COLUMN
  NAME                       = TIME_TAG
  COLUMN_NUMBER              = 6
```

```
     START_BYTE              = 23
     BYTES                   = 13
     DATA_TYPE               = ASCII_REAL
     FORMAT                  = "F13.3"
     DESCRIPTION             = "A derived value for the timetag associated with the
         x,y,z sample in each record. The derived value is created by the
         following formula:
         MET + 0.05 * delta_ts + (dt_sample)*(I-1).
         MET is the mission elapsed time for the entire science packet.
         delta_ts is the delta time in seconds between the MET and
         the first sample in the downloaded science packet.
         dt_sample is the time between samples in seconds and given by
         dt_sample = 1/sample_rate where sample_rate is the reported
         sample rate in samples per second.
         I is the incremental counter for each data sample in the
         science packet. I=1 is the first sample in the packet.
     "
   END_OBJECT               = COLUMN

   OBJECT                   = COLUMN
     NAME                    = ACTUAL_RANGE
     COLUMN_NUMBER           = 7
     START_BYTE              = 37
     BYTES                   = 1
     DATA_TYPE               = ASCII_INTEGER
     FORMAT                  = "I1"
     DESCRIPTION             = "Actual measurement range used by MAG: =0 (1530 nT full
         scale), =1 (51300 nT full scale)."
   END_OBJECT               = COLUMN

   OBJECT                   = COLUMN
     NAME                    = SAMPLE_RATE
     COLUMN_NUMBER           = 8
     START_BYTE              = 39
     BYTES                   = 5
     DATA_TYPE               = ASCII_REAL
     FORMAT                  = "F5.2"
     DESCRIPTION             = "Sample rate used by MAG in units of samples per
second."
   END_OBJECT               = COLUMN

   OBJECT                   = COLUMN
     NAME                    = BX_SENSOR
     COLUMN_NUMBER           = 9
     START_BYTE              = 45
     BYTES                   = 10
     DATA_TYPE               = ASCII_REAL
     FORMAT                  = "F10.3"
     DESCRIPTION             = "X axis magnetic field value in sensor coordinates
       in units of nano-Tesla."
   END_OBJECT               = COLUMN

   OBJECT                   = COLUMN
     NAME                    = BY_SENSOR
     COLUMN_NUMBER           = 10
     START_BYTE              = 56
     BYTES                   = 10
     DATA_TYPE               = ASCII_REAL
     FORMAT                  = "F10.3"
     DESCRIPTION             = "Y axis magnetic field value in sensor coordinates
       in units of nano-Tesla."
   END_OBJECT               = COLUMN

   OBJECT                   = COLUMN
     NAME                    = BZ_SENSOR
     COLUMN_NUMBER           = 11
     START_BYTE              = 67
     BYTES                   = 10
     DATA_TYPE               = ASCII_REAL
     FORMAT                  = "F10.3"
     DESCRIPTION             = "Z axis magnetic field value in sensor coordinates
```

```
          in units of nano-Tesla."
  END_OBJECT                      = COLUMN

  OBJECT                          = COLUMN
    NAME                          = BX_SPACECRAFT
    COLUMN_NUMBER                 = 12
    START_BYTE                    = 78
    BYTES                         = 10
    DATA_TYPE                     = ASCII_REAL
    FORMAT                        = "F10.3"
    DESCRIPTION                   = "X axis magnetic field value in spacecraft coordinates
          in units of nano-Tesla."
  END_OBJECT                      = COLUMN

  OBJECT                          = COLUMN
    NAME                          = BY_SPACECRAFT
    COLUMN_NUMBER                 = 13
    START_BYTE                    = 89
    BYTES                         = 10
    DATA_TYPE                     = ASCII_REAL
    FORMAT                        = "F10.3"
    DESCRIPTION                   = "Y axis magnetic field value in spacecraft coordinates
          in units of nano-Tesla."
  END_OBJECT                      = COLUMN

  OBJECT                          = COLUMN
    NAME                          = BZ_SPACECRAFT
    COLUMN_NUMBER                 = 14
    START_BYTE                    = 100
    BYTES                         = 10
    DATA_TYPE                     = ASCII_REAL
    FORMAT                        = "F10.3"
    DESCRIPTION                   = "Z axis magnetic field value in spacecraft coordinates
          in units of nano-Tesla."
  END_OBJECT                      = COLUMN

END_OBJECT                        = TABLE
END
```

8.2 Appendix – MAG J2000 Coordinates Science CDR PDS Label

```
PDS_VERSION_ID                  = PDS3

/*** FILE FORMAT ***/
RECORD_TYPE                     = FIXED_LENGTH
RECORD_BYTES                    = 115
FILE_RECORDS                    = <file_records>
^TABLE                          = "<file_name>"

/*** GENERAL DATA DESCRIPTION PARAMETERS ***/
DATA_SET_ID                     = "MESS-E/V/H/SW-MAG-3-CDR-CALIBRATED-V1.0"
INSTRUMENT_HOST_NAME            = "MESSENGER"
INSTRUMENT_NAME                 = "MAGNETOMETER"
INSTRUMENT_ID                   = "MAG"
PRODUCT_ID                      = <product_id>
SOURCE_PRODUCT_ID               = <source_product_id>
PRODUCT_VERSION_ID              = "<product_version_id>"
PRODUCT_CREATION_TIME           = <product_creation_time>
PRODUCT_TYPE                    = "CDR"
STANDARD_DATA_PRODUCT_ID        = "MAGJ2KSCI"
SOFTWARE_NAME                   = "MSGR_MAG_EDR2CDR"
SOFTWARE_VERSION_ID             = "1.0"

MISSION_PHASE_NAME              = "<mission_phase_name>"
TARGET_NAME                     = "<target_name>"
START_TIME                      = <start_time>
STOP_TIME                       = <stop_time>
SPACECRAFT_CLOCK_START_COUNT    = <spacecraft_clock_start_time>
SPACECRAFT_CLOCK_STOP_COUNT     = <spacecraft_clock_start_time>

OBJECT                          = TABLE
```

```
COLUMNS                       = 12
INTERCHANGE_FORMAT            = ASCII
ROW_BYTES                     = 115
ROWS                          = <rows>
DESCRIPTION                   = "
  The table contains the timetags, spacecraft position, and 3-axis calibrated
  samples of the magnetic field in J2000 coordinates in units of nano-Tesla.
  The sampling rate is commandable and can vary. The table contains data from
  MAG science packets generated on a given day; data from each packet will be
  stored as one row in the ASCII table. START_TIME and STOP_TIME correspond to
  the TIME_TAG values of the first row and last row (respectively) in the table."

OBJECT                        = COLUMN
  NAME                        = YEAR
  COLUMN_NUMBER               = 1
  START_BYTE                  = 1
  BYTES                       = 4
  DATA_TYPE                   = ASCII_INTEGER
  FORMAT                      = "I4"
  DESCRIPTION                 = "Year associated with the magnetic field samples
        Bx, By, Bz in each record."
END_OBJECT = COLUMN

OBJECT                        = COLUMN
  NAME                        = DAY_OF_YEAR
  COLUMN_NUMBER               = 2
  START_BYTE                  = 6
  BYTES                       = 3
  DATA_TYPE                   = ASCII_INTEGER
  FORMAT                      = "I3"
  DESCRIPTION                 = "Day of year associated with the magnetic field samples
        Bx, By, Bz in each record."
END_OBJECT = COLUMN

OBJECT                        = COLUMN
  NAME                        = HOUR
  COLUMN_NUMBER               = 3
  START_BYTE                  = 10
  BYTES                       = 2
  DATA_TYPE                   = ASCII_INTEGER
  FORMAT                      = "I2"
  DESCRIPTION                 = "Hour associated with the magnetic field samples
        Bx, By, Bz in each record."
END_OBJECT = COLUMN

OBJECT                        = COLUMN
  NAME                        = MINUTE
  COLUMN_NUMBER               = 4
  START_BYTE                  = 13
  BYTES                       = 2
  DATA_TYPE                   = ASCII_INTEGER
  FORMAT                      = "I2"
  DESCRIPTION                 = "Minute associated with the magnetic field samples
        Bx, By, Bz in each record."
END_OBJECT = COLUMN

OBJECT                        = COLUMN
  NAME                        = SECOND
  COLUMN_NUMBER               = 5
  START_BYTE                  = 16
  BYTES                       = 6
  DATA_TYPE                   = ASCII_REAL
  FORMAT                      = "F6.3"
  DESCRIPTION                 = "Second associated with the magnetic field samples
        Bx, By, Bz in each record."
END_OBJECT = COLUMN

OBJECT                        = COLUMN
  NAME                        = TIME_TAG
  COLUMN_NUMBER               = 6
  START_BYTE                  = 23
```

```
    BYTES                   = 13
    DATA_TYPE               = ASCII_REAL
    FORMAT                  = "F13.3"
    DESCRIPTION             = "A derived value for the timetag associated with the
        x,y,z sample in each record. The derived value is created by the
        following formula:
        MET + 0.05 * delta_ts + (dt_sample)*(I-1).
        MET is the mission elapsed time for the entire science packet.
        delta_ts is the delta time in seconds between the MET and
        the first sample in the downloaded science packet.
        dt_sample is the time between samples in seconds and given by
        dt_sample = 1/sample_rate where sample_rate is the reported
        sample rate in samples per second.
        I is the incremental counter for each data sample in the
        science packet. I=1 is the first sample in the packet.
      "
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                    = X_J2000
    COLUMN_NUMBER           = 7
    START_BYTE              = 37
    BYTES                   = 14
    DATA_TYPE               = ASCII_REAL
    FORMAT                  = "F14.3"
    DESCRIPTION             = "X position in J2000 coordinates in units of
kilometers."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                    = Y_J2000
    COLUMN_NUMBER           = 8
    START_BYTE              = 52
    BYTES                   = 14
    DATA_TYPE               = ASCII_REAL
    FORMAT                  = "F14.3"
    DESCRIPTION             = "Y position in J2000 coordinates in units of
kilometers."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                    = Z_J2000
    COLUMN_NUMBER           = 9
    START_BYTE              = 67
    BYTES                   = 14
    DATA_TYPE               = ASCII_REAL
    FORMAT                  = "F14.3"
    DESCRIPTION             = "Z position in J2000 coordinates in units of
kilometers."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                    = BX_J2000
    COLUMN_NUMBER           = 10
    START_BYTE              = 82
    BYTES                   = 10
    DATA_TYPE               = ASCII_REAL
    FORMAT                  = "F10.3"
    DESCRIPTION             = "X axis magnetic field value in J2000 coordinates in
        units of nano-Tesla."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                    = BY_J2000
    COLUMN_NUMBER           = 11
    START_BYTE              = 93
    BYTES                   = 10
    DATA_TYPE               = ASCII_REAL
    FORMAT                  = "F10.3"
    DESCRIPTION             = "Y axis magnetic field value in J2000 coordinates in
        units of nano-Tesla."
```

```
  END_OBJECT                   = COLUMN

  OBJECT                       = COLUMN
    NAME                       = BZ_J2000
    COLUMN_NUMBER              = 12
    START_BYTE                 = 104
    BYTES                      = 10
    DATA_TYPE                  = ASCII_REAL
    FORMAT                     = "F10.3"
    DESCRIPTION                = "Z axis magnetic field value in J2000 coordinates in
          units of nano-Tesla."
  END_OBJECT                   = COLUMN

END_OBJECT                     = TABLE
END
```

8.3 Appendix – MAG MSO Coordinates Science CDR PDS Label

```
PDS_VERSION_ID                 = PDS3

/*** FILE FORMAT ***/
RECORD_TYPE                    = FIXED_LENGTH
RECORD_BYTES                   = 115
FILE_RECORDS                   = <file_records>
^TABLE                         = "<file_name>"

/*** GENERAL DATA DESCRIPTION PARAMETERS ***/
DATA_SET_ID                    = "MESS-E/V/H/SW-MAG-3-CDR-CALIBRATED-V1.0"
INSTRUMENT_HOST_NAME           = "MESSENGER"
INSTRUMENT_NAME                = "MAGNETOMETER"
INSTRUMENT_ID                  = "MAG"
PRODUCT_ID                     = <product_id>
SOURCE_PRODUCT_ID              = <source_product_id>
PRODUCT_VERSION_ID             = "<product_version_id>"
PRODUCT_CREATION_TIME          = <product_creation_time>
PRODUCT_TYPE                   = "CDR"
STANDARD_DATA_PRODUCT_ID       = "MAGMSOSCI"
SOFTWARE_NAME                  = "MSGR_MAG_EDR2CDR"
SOFTWARE_VERSION_ID            = "1.0"

MISSION_PHASE_NAME             = "<mission_phase_name>"
TARGET_NAME                    = "<target_name>"
START_TIME                     = <start_time>
STOP_TIME                      = <stop_time>
SPACECRAFT_CLOCK_START_COUNT   = <spacecraft_clock_start_time>
SPACECRAFT_CLOCK_STOP_COUNT    = <spacecraft_clock_start_time>

OBJECT                         = TABLE
  COLUMNS                      = 12
  INTERCHANGE_FORMAT           = ASCII
  ROW_BYTES                    = 115
  ROWS                         = <rows>
  DESCRIPTION                  = "
    The table contains the timetags, spacecraft position, and 3-axis calibrated
    samples of the magnetic field in Mercury solar orbital (MSO) coordinates in
    units of nano-Tesla. The sampling rate is commandable and can vary. The table
    contains data from MAG science packets generated on a given day; data from
    each packet will be stored as one row in the ASCII table. START_TIME and
    STOP_TIME correspond to the TIME_TAG values of the first row and last row
    (respectively) in the table."

  OBJECT                       = COLUMN
    NAME                       = YEAR
    COLUMN_NUMBER              = 1
    START_BYTE                 = 1
    BYTES                      = 4
    DATA_TYPE                  = ASCII_INTEGER
    FORMAT                     = "I4"
    DESCRIPTION                = "Year associated with the magnetic field samples
          Bx, By, Bz in each record."
  END_OBJECT = COLUMN
```

```
OBJECT                    = COLUMN
  NAME                    = DAY_OF_YEAR
  COLUMN_NUMBER           = 2
  START_BYTE              = 6
  BYTES                   = 3
  DATA_TYPE               = ASCII_INTEGER
  FORMAT                  = "I3"
  DESCRIPTION             = "Day of year associated with the magnetic field samples
        Bx, By, Bz in each record."
END_OBJECT = COLUMN

OBJECT                    = COLUMN
  NAME                    = HOUR
  COLUMN_NUMBER           = 3
  START_BYTE              = 10
  BYTES                   = 2
  DATA_TYPE               = ASCII_INTEGER
  FORMAT                  = "I2"
  DESCRIPTION             = "Hour associated with the magnetic field samples
        Bx, By, Bz in each record."
END_OBJECT = COLUMN

OBJECT                    = COLUMN
  NAME                    = MINUTE
  COLUMN_NUMBER           = 4
  START_BYTE              = 13
  BYTES                   = 2
  DATA_TYPE               = ASCII_INTEGER
  FORMAT                  = "I2"
  DESCRIPTION             = "Minute associated with the magnetic field samples
        Bx, By, Bz in each record."
END_OBJECT = COLUMN

OBJECT                    = COLUMN
  NAME                    = SECOND
  COLUMN_NUMBER           = 5
  START_BYTE              = 16
  BYTES                   = 6
  DATA_TYPE               = ASCII_REAL
  FORMAT                  = "F6.3"
  DESCRIPTION             = "Second associated with the magnetic field samples
        Bx, By, Bz in each record."
END_OBJECT = COLUMN

OBJECT                    = COLUMN
  NAME                    = TIME_TAG
  COLUMN_NUMBER           = 6
  START_BYTE              = 23
  BYTES                   = 13
  DATA_TYPE               = ASCII_REAL
  FORMAT                  = "F13.3"
  DESCRIPTION             = "A derived value for the timetag associated with the
        x,y,z sample in each record. The derived value is created by the
        following formula:
        MET + 0.05 * delta_ts + (dt_sample)*(I-1).
        MET is the mission elapsed time for the entire science packet.
        delta_ts is the delta time in seconds between the MET and
        the first sample in the downloaded science packet.
        dt_sample is the time between samples in seconds and given by
        dt_sample = 1/sample_rate where sample_rate is the reported
        sample rate in samples per second.
        I is the incremental counter for each data sample in the
        science packet. I=1 is the first sample in the packet.
  "
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                    = X_MSO
  COLUMN_NUMBER           = 7
  START_BYTE              = 37
```

```
      BYTES                     = 14
      DATA_TYPE                 = ASCII_REAL
      FORMAT                    = "F14.3"
      DESCRIPTION               = "X position in Mercury solar orbital (MSO)
            coordinates in units of kilometers."
    END_OBJECT                  = COLUMN

    OBJECT                      = COLUMN
      NAME                      = Y_MSO
      COLUMN_NUMBER             = 8
      START_BYTE                = 52
      BYTES                     = 14
      DATA_TYPE                 = ASCII_REAL
      FORMAT                    = "F14.3"
      DESCRIPTION               = "Y position in Mercury solar orbital (MSO)
            coordinates in units of kilometers."
    END_OBJECT                  = COLUMN

    OBJECT                      = COLUMN
      NAME                      = Z_MSO
      COLUMN_NUMBER             = 9
      START_BYTE                = 67
      BYTES                     = 14
      DATA_TYPE                 = ASCII_REAL
      FORMAT                    = "F14.3"
      DESCRIPTION               = "Z position in Mercury solar orbital (MSO)
            coordinates in units of kilometers."
    END_OBJECT                  = COLUMN

    OBJECT                      = COLUMN
      NAME                      = BX_MSO
      COLUMN_NUMBER             = 10
      START_BYTE                = 82
      BYTES                     = 10
      DATA_TYPE                 = ASCII_REAL
      FORMAT                    = "F10.3"
      DESCRIPTION               = "X axis magnetic field value in Mercury
          solar orbital (MSO) coordinates in units of nano-Tesla."
    END_OBJECT                  = COLUMN

    OBJECT                      = COLUMN
      NAME                      = BY_MSO
      COLUMN_NUMBER             = 11
      START_BYTE                = 93
      BYTES                     = 10
      DATA_TYPE                 = ASCII_REAL
      FORMAT                    = "F10.3"
      DESCRIPTION               = "Y axis magnetic field value in Mercury
          solar orbital (MSO) coordinates in units of nano-Tesla."
    END_OBJECT                  = COLUMN

    OBJECT                      = COLUMN
      NAME                      = BZ_MSO
      COLUMN_NUMBER             = 12
      START_BYTE                = 104
      BYTES                     = 10
      DATA_TYPE                 = ASCII_REAL
      FORMAT                    = "F10.3"
      DESCRIPTION               = "Z axis magnetic field value in Mercury
          solar orbital (MSO) coordinates in units of nano-Tesla."
    END_OBJECT                  = COLUMN

END_OBJECT                      = TABLE
END
```

8.4 Appendix – MAG MBF Coordinates Science CDR PDS Label

```
PDS_VERSION_ID                  = PDS3

/*** FILE FORMAT ***/
RECORD_TYPE                     = FIXED_LENGTH
```

```
RECORD_BYTES                 = 115
FILE_RECORDS                 = <file_records>
^TABLE                       = "<file_name>"

/*** GENERAL DATA DESCRIPTION PARAMETERS ***/
DATA_SET_ID                  = "MESS-E/V/H/SW-MAG-3-CDR-CALIBRATED-V1.0"
INSTRUMENT_HOST_NAME         = "MESSENGER"
INSTRUMENT_NAME              = "MAGNETOMETER"
INSTRUMENT_ID                = "MAG"
PRODUCT_ID                   = <product_id>
SOURCE_PRODUCT_ID            = <source_product_id>
PRODUCT_VERSION_ID           = "<product_version_id>"
PRODUCT_CREATION_TIME        = <product_creation_time>
PRODUCT_TYPE                 = "CDR"
STANDARD_DATA_PRODUCT_ID     = "MAGMBFSCI"
SOFTWARE_NAME                = "MSGR_MAG_EDR2CDR"
SOFTWARE_VERSION_ID          = "1.0"

MISSION_PHASE_NAME           = "<mission_phase_name>"
TARGET_NAME                  = "<target_name>"
START_TIME                   = <start_time>
STOP_TIME                    = <stop_time>
SPACECRAFT_CLOCK_START_COUNT = <spacecraft_clock_start_time>
SPACECRAFT_CLOCK_STOP_COUNT  = <spacecraft_clock_start_time>

OBJECT                       = TABLE
  COLUMNS                    = 12
  INTERCHANGE_FORMAT         = ASCII
  ROW_BYTES                  = 115
  ROWS                       = <rows>
  DESCRIPTION                = "
    The table contains the timetags, spacecraft position, and 3-axis calibrated
    samples of the magnetic field in Mercury body fixed (MBF) coordinates in
    units of nano-Tesla. The sampling rate is commandable and can vary. The table
    contains data from MAG science packets generated on a given day; data from
    each packet will be stored as one row in the ASCII table. START_TIME and
    STOP_TIME correspond to the TIME_TAG values of the first row and last row
    (respectively) in the table."

  OBJECT                     = COLUMN
    NAME                     = YEAR
    COLUMN_NUMBER            = 1
    START_BYTE               = 1
    BYTES                    = 4
    DATA_TYPE                = ASCII_INTEGER
    FORMAT                   = "I4"
    DESCRIPTION              = "Year associated with the magnetic field samples
          Bx, By, Bz in each record."
  END_OBJECT = COLUMN

  OBJECT                     = COLUMN
    NAME                     = DAY_OF_YEAR
    COLUMN_NUMBER            = 2
    START_BYTE               = 6
    BYTES                    = 3
    DATA_TYPE                = ASCII_INTEGER
    FORMAT                   = "I3"
    DESCRIPTION              = "Day of year associated with the magnetic field samples
          Bx, By, Bz in each record."
  END_OBJECT = COLUMN

  OBJECT                     = COLUMN
    NAME                     = HOUR
    COLUMN_NUMBER            = 3
    START_BYTE               = 10
    BYTES                    = 2
    DATA_TYPE                = ASCII_INTEGER
    FORMAT                   = "I2"
    DESCRIPTION              = "Hour associated with the magnetic field samples
          Bx, By, Bz in each record."
  END_OBJECT = COLUMN
```

```
OBJECT                        = COLUMN
  NAME                        = MINUTE
  COLUMN_NUMBER               = 4
  START_BYTE                  = 13
  BYTES                       = 2
  DATA_TYPE                   = ASCII_INTEGER
  FORMAT                      = "I2"
  DESCRIPTION                 = "Minute associated with the magnetic field samples
        Bx, By, Bz in each record."
END_OBJECT = COLUMN

OBJECT                        = COLUMN
  NAME                        = SECOND
  COLUMN_NUMBER               = 5
  START_BYTE                  = 16
  BYTES                       = 6
  DATA_TYPE                   = ASCII_REAL
  FORMAT                      = "F6.3"
  DESCRIPTION                 = "Second associated with the magnetic field samples
        Bx, By, Bz in each record."
END_OBJECT = COLUMN

OBJECT                        = COLUMN
  NAME                        = TIME_TAG
  COLUMN_NUMBER               = 6
  START_BYTE                  = 23
  BYTES                       = 13
  DATA_TYPE                   = ASCII_REAL
  FORMAT                      = "F13.3"
  DESCRIPTION                 = "A derived value for the timetag associated with the
        x,y,z sample in each record. The derived value is created by the
        following formula:
        MET + 0.05 * delta_ts + (dt_sample)*(I-1).
        MET is the mission elapsed time for the entire science packet.
        delta_ts is the delta time in seconds between the MET and
        the first sample in the downloaded science packet.
        dt_sample is the time between samples in seconds and given by
        dt_sample = 1/sample_rate where sample_rate is the reported
        sample rate in samples per second.
        I is the incremental counter for each data sample in the
        science packet. I=1 is the first sample in the packet.
  "
END_OBJECT                    = COLUMN

OBJECT                        = COLUMN
  NAME                        = X_MBF
  COLUMN_NUMBER               = 7
  START_BYTE                  = 37
  BYTES                       = 14
  DATA_TYPE                   = ASCII_REAL
  FORMAT                      = "F14.3"
  DESCRIPTION                 = "X position in Mercury body-fixed (MBF)
        coordinates in units of kilometers."
END_OBJECT                    = COLUMN

OBJECT                        = COLUMN
  NAME                        = Y_MBF
  COLUMN_NUMBER               = 8
  START_BYTE                  = 52
  BYTES                       = 14
  DATA_TYPE                   = ASCII_REAL
  FORMAT                      = "F14.3"
  DESCRIPTION                 = "Y position in Mercury body-fixed (MBF)
        coordinates in units of kilometers."
END_OBJECT                    = COLUMN

OBJECT                        = COLUMN
  NAME                        = Z_MBF
  COLUMN_NUMBER               = 9
  START_BYTE                  = 67
```

```
      BYTES                    = 14
      DATA_TYPE                = ASCII_REAL
      FORMAT                   = "F14.3"
      DESCRIPTION              = "Z position in Mercury body-fixed (MBF)
          coordinates in units of kilometers."
    END_OBJECT                 = COLUMN

    OBJECT                     = COLUMN
      NAME                     = BX_MBF
      COLUMN_NUMBER            = 10
      START_BYTE               = 82
      BYTES                    = 10
      DATA_TYPE                = ASCII_REAL
      FORMAT                   = "F10.3"
      DESCRIPTION              = "X axis magnetic field value in Mercury
          body-fixed (MBF) coordinates in units of nano-Tesla."
    END_OBJECT                 = COLUMN

    OBJECT                     = COLUMN
      NAME                     = BY_MBF
      COLUMN_NUMBER            = 11
      START_BYTE               = 93
      BYTES                    = 10
      DATA_TYPE                = ASCII_REAL
      FORMAT                   = "F10.3"
      DESCRIPTION              = "Y axis magnetic field value in Mercury
          body-fixed (MBF) coordinates in units of nano-Tesla."
    END_OBJECT                 = COLUMN

    OBJECT                     = COLUMN
      NAME                     = BZ_MBF
      COLUMN_NUMBER            = 12
      START_BYTE               = 104
      BYTES                    = 10
      DATA_TYPE                = ASCII_REAL
      FORMAT                   = "F10.3"
      DESCRIPTION              = "Z axis magnetic field value in Mercury
          body-fixed (MBF) coordinates in units of nano-Tesla."
    END_OBJECT                 = COLUMN

END_OBJECT                     = TABLE
END
```

8.5 Appendix – MAG RTN Coordinates Science CDR PDS Label

```
PDS_VERSION_ID                 = PDS3

/*** FILE FORMAT ***/
RECORD_TYPE                    = FIXED_LENGTH
RECORD_BYTES                   = 115
FILE_RECORDS                   = 85996
^TABLE                         = "MAGRTNSCI07160_V01.TAB"

/*** GENERAL DATA DESCRIPTION PARAMETERS ***/
DATA_SET_ID                    = "[tbd]"
INSTRUMENT_HOST_NAME           = "MESSENGER"
INSTRUMENT_NAME                = "MAGNETOMETER"
INSTRUMENT_ID                  = "MAG"
PRODUCT_ID                     = "MAGRTNSCI07160"
SOURCE_PRODUCT_ID              = "MAGSCI071600001"
PRODUCT_VERSION_ID             = "V01"
PRODUCT_CREATION_TIME          = 2008-02-15T16:39:00
PRODUCT_TYPE                   = "CDR"
STANDARD_DATA_PRODUCT_ID       = "MAGRTNSCI"
SOFTWARE_NAME                  = "MSGR_MAG_EDR2CDR"
SOFTWARE_VERSION_ID            = "1.0"

MISSION_PHASE_NAME             = "VENUS 2 FLYBY"
TARGET_NAME                    = "VENUS"
START_TIME                     = 2007-06-09T00:01:38
STOP_TIME                      = 2007-06-09T00:01:41
```

```
SPACECRAFT_CLOCK_START_COUNT   = 89834625
SPACECRAFT_CLOCK_STOP_COUNT    = 89921028
OBJECT                         = TABLE
  COLUMNS                      = 12
  INTERCHANGE_FORMAT           = ASCII
  ROW_BYTES                    = 99
  ROWS                         = 85996
  DESCRIPTION                  = "
    The table contains the timetags and 3-axis calibrated samples of the magnetic
    field in heliospheric RTN coordinates in units of nano-Tesla, Br, Bt, Bn.
    The spacecraft position is identified by radial distance from the Sun, latitude
    above the ecliptic plane, and azimuth with respect to the Earth-Sun line in the
    ecliptic plane. The sampling rate is commandable and can vary. The table contains
    data from MAG science packets generated on a given day; data from each packet
    will be stored as one row in the ASCII table. START_TIME and STOP_TIME correspond
    to the TIME_TAG values of the first row and last row (respectively) in the table."

  OBJECT                       = COLUMN
    NAME                       = YEAR
    COLUMN_NUMBER              = 1
    START_BYTE                 = 1
    BYTES                      = 4
    DATA_TYPE                  = ASCII_INTEGER
    FORMAT                     = "I4"
    DESCRIPTION                = "Year associated with the magnetic field samples
            Br, Bt, Bn in each record."
  END_OBJECT = COLUMN

  OBJECT                       = COLUMN
    NAME                       = DAY_OF_YEAR
    COLUMN_NUMBER              = 2
    START_BYTE                 = 6
    BYTES                      = 3
    DATA_TYPE                  = ASCII_INTEGER
    FORMAT                     = "I3"
    DESCRIPTION                = "Day of year associated with the magnetic field samples
            Br, Bt, Bn in each record."
  END_OBJECT = COLUMN

  OBJECT                       = COLUMN
    NAME                       = HOUR
    COLUMN_NUMBER              = 3
    START_BYTE                 = 10
    BYTES                      = 2
    DATA_TYPE                  = ASCII_INTEGER
    FORMAT                     = "I2"
    DESCRIPTION                = "Hour associated with the magnetic field samples
            Br, Bt, Bn in each record."
  END_OBJECT = COLUMN

  OBJECT                       = COLUMN
    NAME                       = MINUTE
    COLUMN_NUMBER              = 4
    START_BYTE                 = 13
    BYTES                      = 2
    DATA_TYPE                  = ASCII_INTEGER
    FORMAT                     = "I2"
    DESCRIPTION                = "Minute associated with the magnetic field samples
            Br, Bt, Bn in each record."
  END_OBJECT = COLUMN

  OBJECT                       = COLUMN
    NAME                       = SECOND
    COLUMN_NUMBER              = 5
    START_BYTE                 = 16
    BYTES                      = 6
    DATA_TYPE                  = ASCII_REAL
    FORMAT                     = "F6.3"
    DESCRIPTION                = "Second associated with the magnetic field samples
            Br, Bt, Bn in each record."
```

```
END_OBJECT = COLUMN

OBJECT                    = COLUMN
  NAME                    = TIME_TAG
  COLUMN_NUMBER           = 6
  START_BYTE              = 23
  BYTES                   = 13
  DATA_TYPE               = ASCII_REAL
  FORMAT                  = "F13.3"
  DESCRIPTION             = "A derived value for the timetag associated with the
        r,t,n sample in each record. The derived value is created by the
        following formula:
        MET + 0.05 * delta_ts + (dt_sample)*(I–1) – latency.
        MET is the mission elapsed time for the entire science packet.
        delta_ts is the delta time in seconds between the MET and
        the first sample in the downloaded science packet.
        dt_sample is the time between samples in seconds and given by
        dt_sample = 1/sample_rate where sample_rate is the reported
        sample rate in samples per second.
        I is the incremental counter for each data sample in the
        science packet. I=1 is the first sample in the packet.
        Latency is the sample rate-dependent delay of the time stamp
        recording relative to the actual time of observation.
        "
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                    = RDIST
  COLUMN_NUMBER           = 7
  START_BYTE              = 37
  BYTES                   = 14
  DATA_TYPE               = ASCII_REAL
  FORMAT                  = "F14.3"
  DESCRIPTION             = "Radial distance of the MESSENGER spacecraft from
        the Sun in units of kilometers."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                    = LATITUDE_ECLIP
  COLUMN_NUMBER           = 8
  START_BYTE              = 52
  BYTES                   = 12
  DATA_TYPE               = ASCII_REAL
  FORMAT                  = "F12.7"
  DESCRIPTION             = "Northward latitude of the MESSENGER spacecraft above
        instantaneous ecliptic plane in units of degrees."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                    = AZIMUTH_ECLIP
  COLUMN_NUMBER           = 9
  START_BYTE              = 65
  BYTES                   = 12
  DATA_TYPE               = ASCII_REAL
  FORMAT                  = "F12.7"
  DESCRIPTION             = "Azimuth angle of the MESSENGER spacecraft in the
        instantaneous ecliptic plane with respect to the Earth-Sun line in units of
        degrees, positive in direction of the Earth's orbital motion."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                    = BR
  COLUMN_NUMBER           = 10
  START_BYTE              = 78
  BYTES                   = 10
  DATA_TYPE               = ASCII_REAL
  FORMAT                  = "F10.3"
  DESCRIPTION             = "Magnetic field value in units of nano-Tesla in Sun-to
        spacecraft direction."
END_OBJECT                = COLUMN
```

```
OBJECT                       = COLUMN
  NAME                       = BT
  COLUMN_NUMBER              = 11
  START_BYTE                 = 89
  BYTES                      = 10
  DATA_TYPE                  = ASCII_REAL
  FORMAT                     = "F10.3"
  DESCRIPTION                = "Magnetic field value in units of nano-Tesla in the
          tangential direction given by the cross product of the Sun spin axis and the
          Sun-to-spacecraft vector."
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = BN
  COLUMN_NUMBER              = 12
  START_BYTE                 = 100
  BYTES                      = 10
  DATA_TYPE                  = ASCII_REAL
  FORMAT                     = "F10.3"
  DESCRIPTION                = "Magnetic field value in units of nano-Tesla in
direction of
          the cross product of the Sun-to-spacecraft vector and the tangential
direction."
  END_OBJECT                 = COLUMN

END_OBJECT                   = TABLE
END
```

8.6 Appendix – MAG AC CDR PDS Label

```
PDS_VERSION_ID               = PDS3

/*** FILE FORMAT ***/
RECORD_TYPE                  = FIXED_LENGTH
RECORD_BYTES                 = 50
FILE_RECORDS                 = <file_records>
^TABLE                       = "<file_name>"

/*** GENERAL DATA DESCRIPTION PARAMETERS ***/
DATA_SET_ID                  = "<data_set_id>"
INSTRUMENT_HOST_NAME         = "MESSENGER"
INSTRUMENT_NAME              = "MAGNETOMETER"
INSTRUMENT_ID                = "MAG"
PRODUCT_ID                   = "<product_id>"
SOURCE_PRODUCT_ID            = "<source_product_id>"
PRODUCT_VERSION_ID           = "<product_version_id>"
PRODUCT_CREATION_TIME        = <product_creation_time>
PRODUCT_TYPE                 = "CDR"
STANDARD_DATA_PRODUCT_ID     = "MAGCALLAC"
SOFTWARE_NAME                = "MSGR_MAG_EDR2CDR"
SOFTWARE_VERSION_ID          = "1.0"

MISSION_PHASE_NAME           = "<mission_phase_name>"
TARGET_NAME                  = "<target_name>"
START_TIME                   = <start_time>
STOP_TIME                    = <stop_time>
SPACECRAFT_CLOCK_START_COUNT = <spacecraft_clock_start_time>
SPACECRAFT_CLOCK_STOP_COUNT  = <spacecraft_clock_stop_time>

OBJECT                       = TABLE
  COLUMNS                    = 8
  INTERCHANGE_FORMAT         = ASCII
  ROW_BYTES                  = 50
  ROWS                       = <rows>
  DESCRIPTION                = "
    The table contains the time tags and average output amplitude in units
    of nano-Tesla of a 1-to-10 Hz bandpass filter for a single magnetometer axis
    selected by command. The sampling rate is 1/s. The table contains data from
    MAG LAC packets generated on a given day with one LAC sample given per row.
    The TIME_TAG corresponds to the center time of the one-second interval used
    to calculate the LAC value. START_TIME and STOP_TIME correspond to the
```

```
    TIME_TAG values of the first row and last row (respectively) in the table."

  NOTE                      = "
<NOTESPLACEHOLDER>  "
  OBJECT                    = COLUMN
    NAME                    = YEAR
    COLUMN_NUMBER           = 1
    START_BYTE              = 1
    BYTES                   = 4
    DATA_TYPE               = ASCII_INTEGER
    FORMAT                  = "I4"
    DESCRIPTION             = "UTC year associated with the LAC sample in each
record."
  END_OBJECT = COLUMN

  OBJECT                    = COLUMN
    NAME                    = DAY_OF_YEAR
    COLUMN_NUMBER           = 2
    START_BYTE              = 6
    BYTES                   = 3
    DATA_TYPE               = ASCII_INTEGER
    FORMAT                  = "I3"
    DESCRIPTION             = "UTC day of year associated with the LAC sample in each
record."
  END_OBJECT = COLUMN

  OBJECT                    = COLUMN
    NAME                    = HOUR
    COLUMN_NUMBER           = 3
    START_BYTE              = 10
    BYTES                   = 2
    DATA_TYPE               = ASCII_INTEGER
    FORMAT                  = "I2"
    DESCRIPTION             = "UTC hour associated with the LAC sample in each
record."
  END_OBJECT = COLUMN

  OBJECT                    = COLUMN
    NAME                    = MINUTE
    COLUMN_NUMBER           = 4
    START_BYTE              = 13
    BYTES                   = 2
    DATA_TYPE               = ASCII_INTEGER
    FORMAT                  = "I2"
    DESCRIPTION             = "UTC minute associated with the LAC sample in each
record."
  END_OBJECT = COLUMN

  OBJECT                    = COLUMN
    NAME                    = SECOND
    COLUMN_NUMBER           = 5
    START_BYTE              = 16
    BYTES                   = 6
    DATA_TYPE               = ASCII_REAL
    FORMAT                  = "F6.3"
    DESCRIPTION             = "UTC second associated with the LAC sample in each
record."
  END_OBJECT = COLUMN

  OBJECT                    = COLUMN
    NAME                    = TIME_TAG
    COLUMN_NUMBER           = 6
    START_BYTE              = 23
    BYTES                   = 13
    DATA_TYPE               = ASCII_REAL
    FORMAT                  = "F13.3"
    DESCRIPTION             = "A derived value for the time tag associated with
      the data values in each record.
      The derived value is created by the following formula:
      MET + 0.05 * delta_ts + 0.5 + (dt_sample)*(i-1)*(num_samples/num_AC).
```

```
        MET is the mission elapsed time for the entire science packet.
        delta_ts is the time in seconds between the MET and the first sample
        in the science packet.
        dt_sample is the time between samples in seconds and is given by
        dt_sample = 1/sample_rate where sample_rate is the reported sample
        rate in samples per second.
        num_samples is number of magnetometer samples.
        num_AC is the number of logAC values.
        i is the incremental counter for each of the logAC values. i=1 is the
        first logAC value in the science packet.
     "
  END_OBJECT                    = COLUMN

  OBJECT                        = COLUMN
    NAME                        = AC_AXIS
    COLUMN_NUMBER               = 7
    START_BYTE                  = 37
    BYTES                       = 1
    DATA_TYPE                   = ASCII_INTEGER
    FORMAT                      = "I1"
    DESCRIPTION   = "AC axis selected.
                     =0 X, =1 Y, =2 Z"
 END_OBJECT = COLUMN

  OBJECT                        = COLUMN
    NAME                        = B_AC
    COLUMN_NUMBER               = 8
    START_BYTE                  = 39
    BYTES                       = 10
    DATA_TYPE                   = ASCII_REAL
    FORMAT                      = "F10.3"
    DESCRIPTION                 = "Average output amplitude in units
            of nano-Tesla of a 1-to-10 Hz bandpass filter for the selected
            magnetometer axis selected by command."
  END_OBJECT                    = COLUMN

END_OBJECT                      = TABLE
END
```

8.7 Appendix – SPICE Kernel Files Used in MESSENGER Data Products

The following SPICE kernel files are used to compute the UTC time and any geometric quantities found in the PDS labels. Kernel files will be generated throughout the mission with a file-naming convention specified by the MESSENGER project. The SPICE kernels are archived separately in the SPICE data volume with the VOLUME_SET_NAME "MESSENGER: GEOMETRY" and the VOLUME_SET_ID "USA_NASA_PDS_MESSNAIF_1001".

*.bsp:
MESSENGER spacecraft ephemeris file. Also known as the Planetary Spacecraft Ephemeris Kernel (SPK) file.

*.**bc:**
MESSENGER spacecraft orientation file. Also known as the Attitude C-Kernel (CK) file.

*.tf:
MESSENGER reference frame file. Also known as the Frames Kernel. Contains the MESSENGER spacecraft, science instrument, and communication antennae frame definitions.

*.ti:
MESSENGER instrument kernel (I-kernel). Contains references to mounting alignment, operating modes, and timing as well as internal and field of view geometry for the MESSENGER Magnetometer.

*.tsc:
MESSENGER spacecraft clock coefficients file. Also known as the Spacecraft Clock Kernel (SCLK) file.

*.tpc:
Planetary constants file. Also known as the Planetary Constants Kernel (PcK) file.

*.tls:
NAIF leapseconds kernel file. Used in conjunction with the SCLK kernel to convert between Universal Time
Coordinated (UTC) and MESSENGER Mission Elapsed Time (MET). Also called the Leap Seconds Kernel (LSK) file.

8.8 Appendix – MAG Instrument Overview

MAG Software Functionality

The MAG software receives vector magnetic field samples, 20 bits per X, Y, and Z axes, from the MAG electronics at 20 Hz. After bias removal, it filters and sub samples this data to generate output data samples at the commanded rate: 0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1, 2, 5, 10 or 20 samples/second. The MAG software consistently builds science records with compressed (if commanded) MAG data obtained from the above processing for transmission to the DPU via CCSDS telemetry packets.

The MAG software collects burst data consisting of 8 minutes of 20 sample/s data during a commandable time period during orbit. The detection is done by passing the field samples of a selected axis from the bias removal logic through a 1 to 10 Hz pass band filter and determining a log AC value from this data. If this value indicates that the magnetic field is fluctuating above a trigger level, burst data over eight consecutive minutes is collected, compressed and sent to the DPU via CCSDS telemetry packets.

The MAG software also controls the MAG electronics via memory mapped I/O. The commands sent to the MAG instrument control the range of the MAG probe and set two calibration modes in the MAG electronics.

Finally, the MAG software collects housekeeping data indicating the state of the MAG instrument and software for packaging into low rate housekeeping (LRH) telemetry packets.

MAG Electronics

MAG is a three-axis ring-core fluxgate magnetometer with low-noise electronics. It is mounted on a 3.6 meter boom in the anti-sunward direction. The MAG has +/-1530 and

+/-51300 nT ranges with 20-bit internal resolution, 17-bit output resolution. (See Figure 5, Figure 6, and Figure 7).

The MAG probe samples X, Y, and Z axes magnetic field values at a rate of 20 samples/s. The data passes through an A/D converter where it is also filtered by the hardware.

The MAG software interfaces with the MAG electronics via memory mapped I/O for data collection, range control, and electronics calibration.

<u>Software External Interfaces and High-level Functionality</u>

A summary of MAG instrument application software high-level functionality is listed below.

    1) DPU Interface
            - receive S/C time and commands from DPU
            - provide instrument state, telemetry, and turn-off requests to DPU
    2) Magnetometer Instrument Interface
            - range control, calibration, science data collection
    3) MAG Field Sample Processing
            - bias removal, anti-alias filtering, output subsampling
    4) Burst Detection and Burst Data Collection.
    5) Science Data and Burst Data Compression
    6) Command Handling
            - command / macro execution
    7) Telemetry Handling
            - generation, buffering, and delivery to DPU
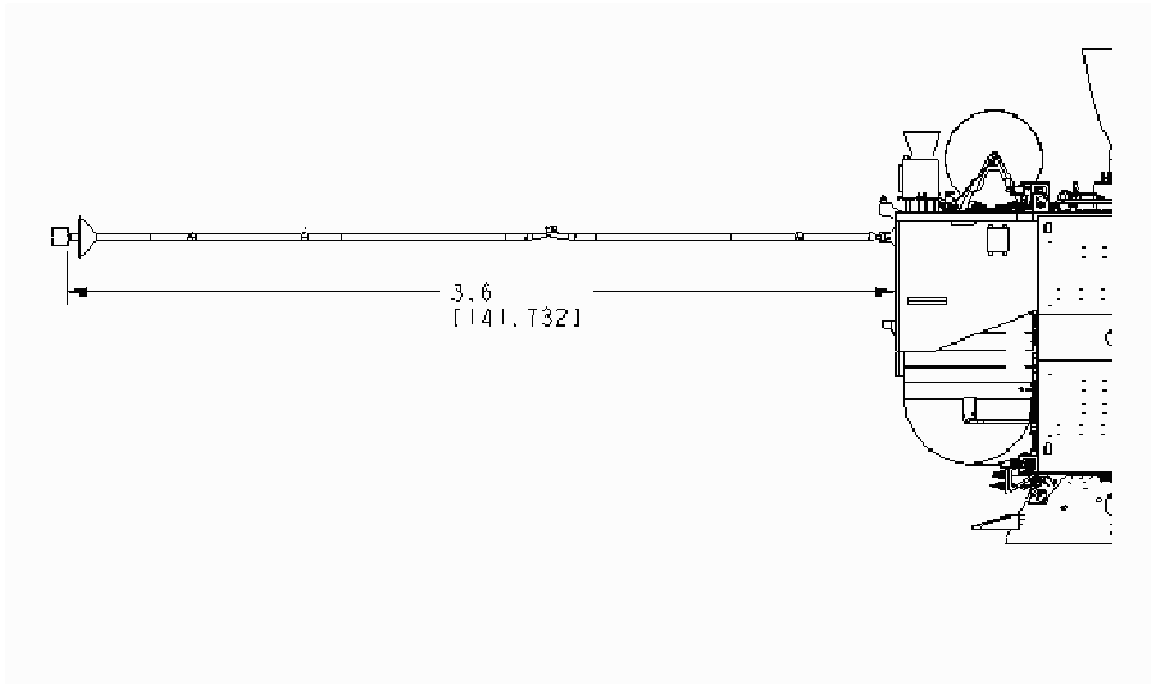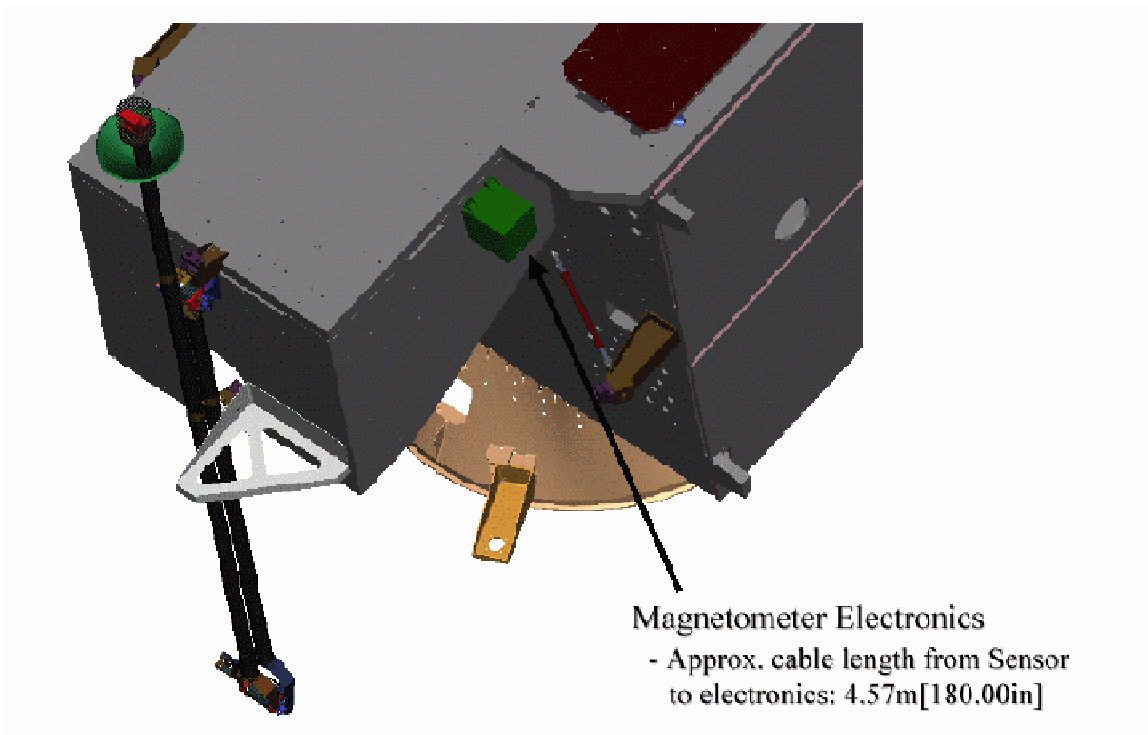   8) Fault Detection and Recovery

Figure 5 Magnetometer Deployment.

Magnetometer Electronics
- Approx. cable length from Sensor
  to electronics: 4.57m[180.00in]

Figure 6 Location of the Magnetometer Electronics.

First Release
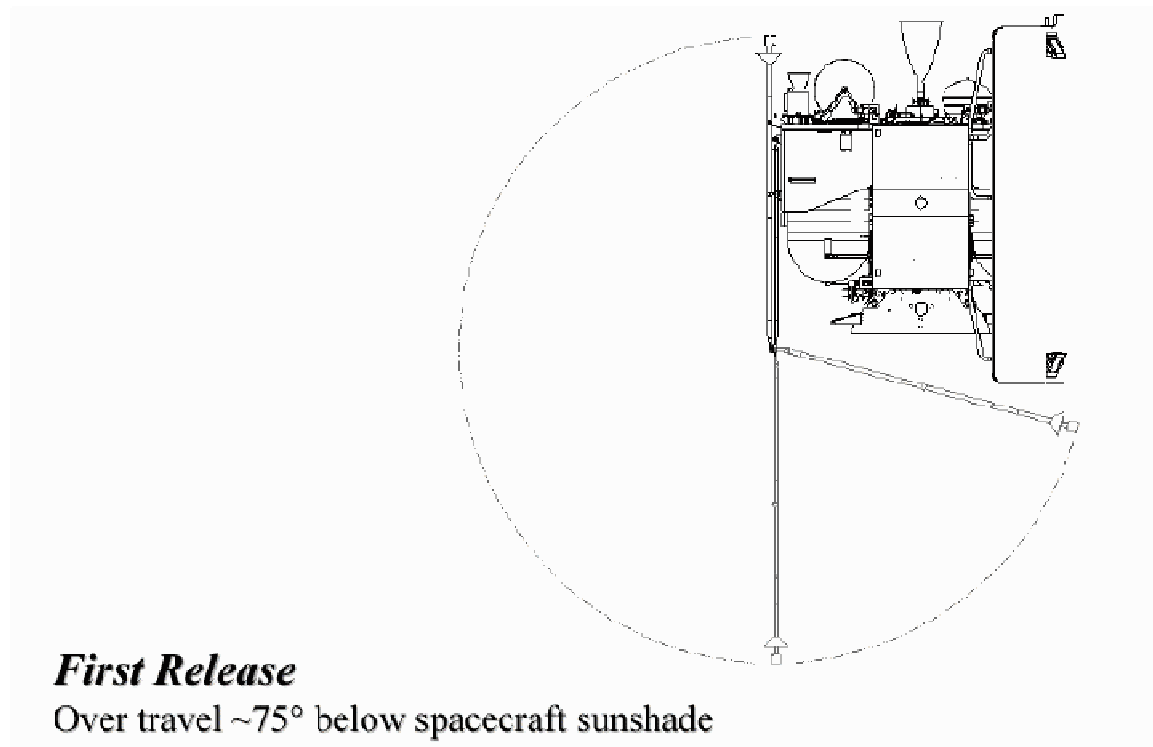Over travel ~75° below spacecraft sunshade

Figure 7 Magnetometer Boom Deployment.

8.9 Appendix – Data Archive Terms

Definition of Terms:

Archive	An archive consists of one or more data sets along with all the documentation and ancillary information needed to understand and use the data. An archive is a logical construct independent of the medium on which it is stored.
Archive volume, archive volume set	A volume is a unit of medium on which data products are stored; for example, one DVD. An archive volume is a volume containing all or part of an archive; that is, data products plus documentation and ancillary files. When an archive spans multiple volumes, they are called an archive volume set. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone.
Data Product	A labeled grouping of data resulting from a scientific observation, usually stored in one file. A product label identifies, describes, and defines the structure of the data. An example of a data product is a planetary image, a spectrum table, or a time series table.
Data Set	An accumulation of data products. A Data set together with supporting documentation and ancillary files is an archive.
Experiment Data Records	NASA Level 0 data for a given instrument; raw data. Same as CODMAC Level 2.
Reduced data records	Science data that have been processed from raw data to NASA Level 1 or higher. See Table for definitions of processing levels.
Standard data product	A data product that has been defined during the proposal and selection process and that is contractually promised by the PI as part of the investigation. Standard data products are generated in a predefined way, using well-understood procedures, and processed in "pipeline" fashion.

8.10 Appendix – CODMAC and NASA Data Levels

CODMAC/NASA Definition of processing levels for science data sets

CODMAC Level	Proc. Type	Data Processing Level Description
1	Raw Data	Telemetry data stream as received at the ground station, with science and engineering data embedded. Corresponds to NASA packet data.
2	Edited Data	Instrument science data (e.g. raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed. Referred to in the MESSENGER program as Experimental Data Records (EDRs). Corresponds to NASA Level 0 data.
3	Calibrated Data	Edited data that are still in units produced by instrument, but have transformed (e.g. calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g. radiances with calibration equations applied). Referred to in the MESSENGER Program as Calibrated Data Records (CDRs). In some cases these also qualify as derived data products (DDRs). Corresponds to NASA Level 1A.
4	Resampled data	Irreversibly transformed (e.g. resampled, remapped, calibrated) values of the instrument measurements (e.g. radiances, magnetic field strength). Referred to in the MESSENGER program as either derived data products (DDPs) or derived analysis products (DAPs). Corresponds to NASA Level 1B.
5	Derived Data	Derived results such as maps, reports, graphics, etc. Corresponds to NASA Levels 2 through 5
6	Ancillary Data	Non-Science data needed to generate calibrated or resampled data sets. Consists of instrument gains, offsets; pointing information for scan platforms, etc.
7	Corrective Data	Other science data needed to interpret space-borne data sets. May include ground based data observations such as soil type or ocean buoy measurements of wind drift.
8	User Description	Description of why the data were required, any peculiarities associated with the data sets., and enough documentation to allow secondary user to extract information from the data.

The above is based on the national research council committee on data management and computation (CODMAC) data levels.

8.11 Appendix – Acronyms

ACT	Applied Coherent technology Corporation
APL	The Johns Hopkins University Applied Physics Laboratory
ASCII	American Standard Code for Information Interchange
CCSDS	Consultative Committee for Space Data Systems
CDR	Calibrated Data Record
CK	Camera Kernel (SPICE)
CoDMAC	Committee on Data Management and Computation
Co-I	Co-Investigator
DN	Digital number, the raw telemetry count
DPU	Data Processing Unit
DSN	Deep Space Network
EDR	Experimental Data Records
EPPS	Energetic Particle and Plasma Spectrometer
ET	Ephemeris Time
FIPS	Fast Imaging Plasma Spectrometer
FOV	Field-of-View
FTP	File Transfer protocol
GC	Geochemistry Group
GP	Geophysics Group
GRNS	Gamma-ray and Neutron Spectrometer
GSFC	Goddard Space Flight Center
I&T	Integration and Test
I2C	Inter-Integrated Circuit
IEM	Integrated Electronic Module

LSK	Leapseconds Kernel (SPICE)
MAG	Magnetometer
MASCS	Mercury Atmospheric and Surface Composition Spectrometer
MDIS	Mercury Dual Imaging System
MESSENGER	MErcury, Surface, Space ENvironment, Geochemistry, and Ranging
MET	Mission Elapsed Time
MLA	Mercury Laser Altimeter
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
PCK	Planetary Constant Kernel (SPICE)
PDS	Planetary Data System
RDR	Reduced Data Record
SCLK	Spacecraft Clock Kernel (SPICE)
SOC	Science Operations Center
SPICE	Spacecraft, Planet, Instrument, C-matrix Events, refers to the kernel files and NAIF Software used to generate viewing geometry
SPK	Spacecraft and Planets Kernel (SPICE)
UTC	Coordinated Universal Time
XRS	X-Ray Spectrometer